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ABSTRACT

Mathematics curricula in Canadian schools, especially at the secondary level, have until now derived much of their content and ways of teaching largely from university mathematics and mathematicians. This feasibility study represents a first step in collecting and analyzing data from hi-tech industries, businesses and organizations. In Phase I, a tentative list of 12 areas which seemed to comprise high technology was developed. In Phase II, a pilot field-study was carried out. Continued progress toward designing an expanded study was made by further examination of the meaning of high technology in practice. It was decided that the term "hi-tech" should mean the creation and use of advanced technology in all major areas of the economy, including research, manufacturing, consulting, service and government sectors. Finally, the relationship and interactions between computer science and mathematics were studied and analyzed to ensure that the instruments used in an expanded study would reflect this significant dimension. The bulk of the document consists of the following appendices which follow seven pages of references: (1) Materials Used in Visits and Discussions; (2) The Design of the Study; (3) A Taxonomy of Activities, Processes, and Skills in Mathematics; (4) Towards an Operational Definition of "Hi-Tech" for Research Purposes; and (5) Computer Science, Mathematics and the School Curriculum. (PK)

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THE MATHEMATICS CURRICULUM AND THE USE OF MATHEMATICAL KNOWLEDGE AND SKILLS IN CANADA IN AN ERA OF HIGH TECHNOLOGY

DOUGLAS H. CRAWFORD

Research & Information Report

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SSHRC Feasibility Study

under Grant No. 410-83-0588

by

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Queen's University, Kingston

CORRIGENDA

Page	Line	Item
14	13	Replace CODE by CODEC
23	6	Replace IV by VI
27	21	Insert "and" between "study" and "instead"
32	Bottom	Delete "in 1983"
Appendix IV	P.16 l. 22	Replace "basing" by "base budgeting"
Appendix IV	P.18 l. 6	Replace "Inteligence" by "Intelligence"

D.H. Crawford
October, 1986

THE MATHEMATICS CURRICULUM AND THE USE OF MATHEMATICAL KNOWLEDGE AND SKILLS IN CANADA IN AN ERA OF HIGH TECHNOLOGY

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Report to the Social Science
and Humanities Research Council of Canada

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Clearly this report owes much to the excellent work and cheerful cooperation of secretaries and typists in the Faculty of Education, Queen's University, in particular Bonnie Knox and Deborah Mills.

Finally, the author wishes to acknowledge the grant made by the Social Science and Humanities Research Council of Canada to enable this feasibility study to be carried out. He particularly appreciated the consideration and understanding he received from council officers when he requested extensions of the study for health and other reasons.

ABSTRACT

Mathematics curricula in Canadian schools, especially at the Secondary level, have until now derived their content and ways of teaching it largely from University mathematics and mathematicians. In an age of increasing change due to high technology, there is an urgent need to discover how and what mathematics is used in hi-tech enterprises so that the results can be fed into a more balanced process of curriculum renewal. This feasibility study represents a first step in collecting and analyzing such data from hi-tech industries, businesses and organizations.

The study was conducted in two Phases: I - August 1983 to May 1984 and II - July 1985 to early summer 1986. Attention was concentrated in Phase I on two basic aspects of the study:

(i) What do we mean by "high-tech"? This is important to know in order to define an appropriate population and sample from which to gather relevant data.

(ii) analysing the meaning, scope and structure of mathematical concepts and processes so as to develop appropriate survey instruments to use in an actual study.

By the end of Phase I, a tentative list of 12 areas which together seemed to comprise high technology had been developed through visits and analysis of relevant materials. In addition, a taxonomy of mathematical activities and processes, which could be used to probe whether such processes were used in high

technology enterprises, had been developed and refined to a usable level.

In Phase II, a pilot field-study using this process taxonomy, a mathematics content taxonomy, and other questionnaire material was carried out at a Northern Telecom manufacturing plant. Forty employees representing all areas of the endeavour from Research and Development through Production to Marketing and Finance, and covering four levels of responsibility, were interviewed using these instruments. The main findings were:

(i) All employees use activities and processes which parallel those of the process taxonomy in planning and carrying out their work.

(ii) The computer is widely used in all the areas and phases of the enterprise - for accessing and retrieving data, and for monitoring and control purposes.

(iii) "Percentage" is perceived to be a centrally important area of the school mathematics curriculum.

(iv) There was general agreement that school mathematics was too theoretical and unrelated to real life, and should be revised in the direction of applications and everyday users of mathematics.

Continued progress toward designing an expanded study was made by further examination of the meaning of high technology in practice. As a result, it was decided that the term "hi-tech"

should be taken to mean the creation and use of advanced technology in all major areas of the economy, including research, manufacturing, consulting, service and government sectors.

A prototype population matrix was also developed inductively from a consideration of prominent Canadian high tech firms so that it could form a model for later choice of firms and organizations to be surveyed.

Finally, the relationship and interactions between computer science and mathematics were studied and analysed to ensure that the instruments used in an expanded study would reflect this significant dimension.

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INTRODUCTION

Origin Of Study And Initial Proposal

The study had its origin in the conviction of the author that too much emphasis was being placed in mathematics curriculum development on the views of University Mathematicians, and too little on the views of employers and leaders in industry. With the increasing impact of the microelectronics revolution, and a second wave of bioengineering development already on the horizon, he felt that the time was right to gain data which can

> "document stable and emerging uses of mathematics in the 1980's as a balancing force in shaping the mathematic curriculum and having such information available for better planning of educational programs in mathematics.
>
> The proposed study should produce real data on the actual and potential uses of mathematics in the coming turbulent years of technological change. This data can then be fed into the process of curriculum renewal, with a strong expectation of improved relevance and meaningfulness for the bulk of students who presently find mathematics boring and/or irrelevant in their adolescent years. To say this is not, however, to deny the power of abstract

mathematical activity which proves time and time again that there is a real life application for the particular area involved." (Crawford, 1982 pp. 3.2,3.3)

The basic objective of the proposed study was to identify, examine and analyse competencies and skills needed in significant areas of Canadian industry and business with a view to assessing their implications for the teaching and learning of mathematics in schools and elsewhere. Initially, data was to be sought by means of selective interviews, personal visits, document analysis, and reading of relevant literature. The major focus was to be on visiting high tech industries to ascertain what mathematics was used, in what ways, and by whom.

An initial conceptual framework positing four levels of need for the use of mathematics in business and industry was suggested as follows:

LEVEL	DESCRIPTION
1.	Mathematics which is basic for all business and industry.
2.	Mathematics for departments common to all businesses, for example, a finance office.
3.	Mathematics common to a sub-set of industry.
4.	Mathematics unique to a particular industry.

A case-study approach, focusing initially on firms in the microelectronics, and possibly the biotechnology industry, was envisaged. Data on mathematical content and methods and their use would then be compiled by means of interview, etc., across firms and types of employee.

The Current Feasibility Study

The original proposal for a 3-year-study was made in October, 1982. Subsequent evaluation was conducted by the appraisers appointed by the Social Sciences Humanity Research Council of Canada, and a one-year grant of $15,000 offered the author in June 1983 for a feasibility study which did not include funding for a research stipend. Final financial arrangements were completed by mid-August, 1983, and the author then engaged a Research Assistant and began the study. Subsequently, because of health problems of both the investigator and Research Assistant, the investigator approached the council in late May, 1984, and received permission to have the grant extended to the end of September, 1985.

Finally, on his return from sabbatical leave in the summer of 1985, he negotiated an additional period of funding and obtained final agreement from the council that the report be submitted by the end of June, 1986.

These comments are made since the postponement and extensions affected the phases in which the research was developed and conducted.

PHASE I AUGUST 1983 - MAY 1984

This phase was one of orientation, exploration, and clarification. A major aspect was a series of visits to and discussions with individuals and small groups in various organizations - national organizations such as the Canadian Advanced Technology Association (CATA), federal government departments such as the Department of Regional Industrial Expansion (DRIE), private firms such as Mitel Corporation and Gandalf Technologies Inc., and university professors and other individuals with educational, technological, or business expertise.

Early Activities Summer/Fall 1983

Activities in this period could be summarized under three headings - professional visits and discussions; initial development of content and process frameworks in mathematics; and attendance at the 4th Canadian Symposium on Instructional Technology in Winnipeg in October, 1983.

1. Visits and Discussions

Significant early visits included those to the Electrical and Electronic Manufacturing Association of Canada (EEMAC) (Ernie Welling) and Canadian Manufacturing Association (CMA) (J. Laurent Thibault). At EEMAC, Mr. Welling showed keen interest

in the study and, as well as suggesting other individuals to consult, has continued to offer advice, especially with respect to the meaning of high technology. In the spring of 1986, he supplied very useful material in this connection and later read draft portions of the report - those on the Northern Telecom Pilot Study and the Appendix relating to an operational definition of "high tech". Mr. Thibault suggested that there was a need to analyse why mathematics is difficult, and that since the Japanese had the highest rate of literacy, some study of their approach would be valuable. He saw two ways of choosing a suitable sample - by industrial classification or by function (production, assembly, marketing). He felt it wise to begin with a large company, and focus on the scientific/technical level. He supplied a list of the members of the CMA R/D committee for further reference.

Colin Patterson, Vice-President of Gandalf Technologices Inc. was at Queen's University for two weeks in November and December, 1983. During that time, the investigator was able to hear him speak and also have a personal discussion with him. Among the views he expressed on these occasions were the following:

(1) Industry is driven by economics. Mathematics is a tool for this but the mathematics used is the minimum needed to understand the economic problems;

(2) The data which is used for working things out is poor

in quality and the process for developing a new product reflects this.

(3) Benefits often come from insignificant improvements.

In reply to queries put to him by the investigator, he had the following comments: Q. what categories of high tech should one use? A. invent your own categories. The easiest categories might be annual sales, rate of growth and number of employees. Another way was to classify by the types of application.

As regards to vertical structure in a firm, he promised to send a organizational chart of Gandalf which according to him had four vertical levels. In regards to the future, Patterson felt that low-skilled jobs will disappear. In order to get a general impression of this, he recommended a visit to the Kanata High Technology Training Association. He saw three major areas where technology would be significant - transportation, materials science, and bio-engineering. Finally, he claimed that it was extremely important that people should be re-educated and re-trained to be able to use leisure. In this connection, he give his opinion that the huge information flow which is developing may not benefit society, that there is a danger of what he called guru self-interest, and that only a very small percentage of society would be using the massive information flow. The future of data communications lies in machine-to-machine communications with applications such as weather prediction, image processing, seismic surveying and income assessment.

On November 24, 1983, a visit was made to Mitel Corporation, Kanata, and discussions held with Les Martin, Director of Special Developments and Ian Grant, Operations Research. Among the suggestions made were the following:

(1) Use Schaum's outline for developing a process/content framework as a basis for developing a questionaire.

(2) Contact Stephen Alvey of Bell Northern who has developed a model of information flow with three axes labelled type of information; process; and originator.

(3) Contact K.E.C. Smith, Dean of Engineering, University of Toronto, and Dr. Michael Caughey, President of the Institute of Advanced Technological Studies, Ottawa.

Finally, the trend to array processing was emphasized and the investigator was supplied with a copy of an article on that theme from the magazine Electronics.

Other useful visits and discussions included the Canadian Advanced Technology (CATA), the Department of Employment and Immigration (DEI), and the Kanata Hi-Tech Training Association. Useful contacts were made, materials were obtained and a feeling for the challenges and stresses accompanying the new technologies in industry was gained as a result. A particularly interesting report was obtained at DEI from Louis Reeves who chaired a survey carried out in the Ottawa-Carleton area in 1981 to determine high tech training needs. Forty-three hi-tech firms with employee

numbers going from 2 - 1200 were surveyed. The questionaire used and some of the results obtained provided useful background material.

2. Conceptual Frameworks

Since a major part of the study depended on a sound knowledge and analysis of mathematical content and mathematical processes which would later be used to develop instruments for data-gathering, the investigator had discussions with several members of the Queen's University mathematics department. In particular, he had discussions with a long-time colleague interested in mathematics education, Norman Rice. As a result, he was able to develop a broad conceptual map of mathematics entitled "Areas and Concepts of Mathematics and Their Relationships which is shown in Appendix I. This map proved useful as a starting point for further discussions and also later in designing the questionnaires for the pilot study conducted in the fall of 1985.

Work was also begun in the summer of 1983 on a classification or taxonomy of mathematical actions and/or activities and processes. Two levels of such processes and activities were envisaged: (1) a set of basic activities at the concrete or manipulative level; and (2), a second set of more composite or complete mathematical processes. This classification was used to develop an initial taxonomy in tabular form. A copy of this is included in Appendix I as part of a hand-out which was used from November, 1983 onwards whenever a

professional visit was made. The other elements in the handout were a summary of the project as it appeared in the SSHRC proposal in October, 1982, and the conceptual map referred to above. It should be noted that at this stage, three composite mathematical activities had been identified namely problem solving, proving, and mathematizing.

3. School Mathematics and Computer Science

A second area of major importance in the continuing evolution of mathematics in general and school mathematics in particular, is the discipline of computer science and its intersection with education. The theme of the 4th Canadian Symposium on Instructional Technology in October, 1983, was Computer Technologies for Productive Learning. Much relevant background knowledge, and a number of excellent contacts were the major outcomes of the symposium for the investigator. The key note address by Denzel Doyle focused on Educational and Technology Transfer. Doyle suggested education could help by (1) forging stronger links with industry; (2) opening up public laboratories to the investment of venture capital and (3) engaging in technology transfer with educational industry. In brief discussion afterwards, he recommended that the investigator contact the Montreal Engineering Company as a leader in high technology. Other informative addresses were by Jim Brahan, National Research Council (NRC), who characterized the developments of CAL in the 1980's as hardware, systems software, authoring, and distribution/delivery systems. By 1990, there

would be a 1 Megabyte chip, with optical storage, and considerable development in artificial intelligence techniques, natural languages, and expert systems. Authoring would move to inputs being in a form appropriate for the application, and networking would be a major factor with flexibility among the four interrelated factors of author, content, software and learner becoming increasingly important.

Gordon Pask spoke on Computer Based Knowledge Representation, and outlined THOUGHT STICKER, a method of representing and manipulating knowable topics and relations between topics in a subject matter or area. This representation has been used successfully in rendering traditionally difficult parts of a subject matter more accessible and in studying individual learning styles. The theoretical basis is Conversational Theory which focuses on student-teacher or small group dialogue. The logic of shared concept and beliefs is used to generate representations called entailment meshes based on this coherent logic, together with two related ingredients, distinction and process.

Focussing The Design Of The Project - Jan. 1984 -June 1984

During the first half of 1984, good progress was made in several areas, especially in conceptualizing the overall plan and design of the study, extending and refining the process taxonomy, and in clarifying the meaning of high-technology. Further

valuable visits were made.

1. The Overall Plan of the Project

In January 1984, the author began to develop a framework for the design and implementation of the pilot study. It consisted of two prongs (i) the conceptual tools and (ii) the definition of the population and sample to which these would be applied. Given the successful completion of this framework, the study could then be conducted, results obtained and analysed, and further improvements and generalizations considered.

In practice, work during the ensuing months was concentrated on this framework. Later, in May 1984, a tentative diagrammatic model of the design phase was developed. A copy of this diagram is given in Appendix 2.

2. Further Development of the Process Taxonomy

This took place during the period February to May 1984, and is discussed in detail in a paper presented at the Fifth International Congress on Mathematical Education in Adelaide, South Australia in August 1984. This paper outlines the development of the taxonomy from the initial list noted earlier to its final form described below. The taxonomy was derived from the work of a number of mathematics educators who have been working in this area since 1971 - particularly in England, U.S.A. and Denmark.

The final taxonomy had two parts - a set of basic activities

or processes such as comparing or representing, arranged sequentially, and a set of five higher order processes arranged in historical order - proving, problem-solving, mathematical modeling, mathematizing, and investigating situations. Finally, an attempt was made to combine these two parts in one diagram, showing both the real world and the world of mathematics, and how the processes involved are related to the two worlds. The fifth higher order process - investigating situations - seems to embody all of the 13 basic sequential "mathematical processes" identified. This conference paper has been reproduced as Appendix III and should be consulted if a more detailed understanding of the taxonomy is desired.

3. The Meaning of Hi-Tech and its Implication for the Design of the Study

Since the study focusses on the implications of "high technology" for mathematics curriculum in schools and elsewhere, it is very important to have an acceptable working definition of "high-tech" to use as a basis in identifying the population to which the study should be applied. This was therefore one of the key points raised in the discussions with individuals and organization in the early stages of the project. Data on hi-tech industry as it appeared in newspapers such as the Toronto Globe and Mail, and in magazines such as High Technology was also collected as deemed appropriate. Appendix IV gives the full story of the quest for the meaning of the term so that it could

be applied as a criterion in choosing appropriate firms and organizations to include in the study. Initially, the focus for the meaning of applied technology seemed to be primarly on computer technology developed as a result of silicon chip technology. By the end of Phase I of the project, a tentative list of 12 areas which might be judged as "hi-tech' in nature had been identified. These were:

- office automation
- computer hardware
- software and software development
- electronics (in general)
- avionics and military technology
- medical technology
- fiber optics, lasers, and microwaves
- communications
- biotechnology
- consumer products
- robotics
- materials

4. Three Significant Visits

Among the numerous visits and discussions, three in in particular are worth summarizing as they yielded particularly useful materials and ideas for both the pilot study and the future proposed expanded study. The visits were to Bell Northern Research (BNR), Ottawa, the Department of Regional Industrial

Expansion (DRIE), Ottawa, and Evert Communications Limited, Ottawa.

A visit paid to Robin (Bonnie) Jackson, Manager, Bell Northern Research (BNR), University Liaison on February 16, 1984, proved most productive and, in fact, led to the choice of Northern Telecon, Belleville, as the site of the pilot study reported later.

Discussions with Mr. Jackson and a later reading of The BNR Story 1956-81, afforded the author an excellent overview of the BNR research organization and its place in the evolution of the very successful tripartite telecommunications leader - Bell Canada Enterprises Northern Telecom and BNR. BNR was the first to put a CODE (COder-DECoder) signal analysis circuit on a single silicon chip in the mid sixties, and has led the way in digital technology since then with switching products, terminals and transmission facilities. Now that the point of diminishing returns in voice transmission technology has been reached, a new era which one might call the era of total communication has arrived. The BNR story has this to say:

> Total communications means using other senses as well as hearing, and using information in other formats as well as voice. The digitization of voice has turned the telecommunications network into a forum in which total communication can occur.

Where does this capability lead?

* To the transmission of all kinds of information over the network.
* To the development of communications products that can process different forms of information simultaneously.
* To the simultaneous processing and presentation on one terminal of information from different sources.
* To the development and introduction of very complicated conferencing arrangements that combine voice, video, and data.
* To the gathering and processing of data for use first in the business environment, then in the home.
* To the use of the telecommunications network as an advertising medium whose terminals can transmit, select, and retain the specific information their owners require.

Technology will be orchestrated to meet these needs, essentially the needs of faster changing and better informed markets. This will likely demand more foresight, boldness, and analytical ability than ever because of the shorter lead times created by technology and because the demands of the marketplace will be more complex and diverse.

(The BNR Story
Ch. 2 1981-1991)

Of 3,118 employed by BNR in July 1983, 2,563 worked in Canada, over 50% of whom had Bachelor's or Higher Degrees, with priority emphasis as follows:

Electrical Engineering and Communications	953
Computer Science	336
Physics, Physical Chemistry and Applied Science	133
Math, Statistics, Information Theory	120

BNR is a systems organization in which there are no ranks and little structure and the "investigatory " culture is crucial. The successful individuals are those who understand fundamentals and can adapt. It is this kind of culture which lies behind the success of BNR which is therefore a strong candidate for inclusion in the final study.

Contact with the Department of Regional Industrial Expansion resulted in a discussion meeting on March 15, 1984, with a group of interested individuals from several government departments. The investigator outlined the aim of the project and obtained excellent feedback and suggestions. For example, the need to clarify the focus of the study - should it be on producers of hi-tech or consumers of hi-tech - was stressed. Several individuals who might be consulted were named and a list of hi-tech areas sent later by the Science Council representative (Aant Elzinga) was very useful as one of the four significant sources of data

used to refine the operational definition of "hi-tech". Additionally, the author has continued to receive the DRIE Journals Canada Commerce and Innovation which contain up-to-date articles and commentaries on hi-tech areas. For example, the November 1983 issue carried two excellent articles on productivity by Henry Traynor. The following quotations still seem relevant in 1986.

> "The job prospects of Canada's entire 11-million workforce may be determined by the levels of computerization employed in each factory, office, depot, departmental store and corner shop."
>
> (H. Traynor)

> "What technology is addressing now is the productivity of the knowledge worker/professional in the same way that CP/M became the standard for early PCs (because CP/M was there first with an installed base)."
>
> (Bill Lipski)
> Executive Vice-President
> BYTEC

Much useful background and orienting information was obtained from a consultative visit on March 15, 1986, to Gordon Hutchison of Evert Communications Ltd. which publishes Third Wave Investing - The Canadian High Technology Investment Review. For him, "hi-tech" means the exploiting of each specialized area of advanced technology. The simplest way to apply this definition is

to equate it with companies having R&D expenditures which are at least 5% of sales. Care, however, must be taken in interpreting R&D spending since "inconsistencies exist in the presentations of R&D expenditure between one company and another" (3rd Wave Investing, Feb. 1984). Much of the Canadian expertise in "hi-tech" lies in applications - particularly in the communications field. But the entrepreneurial element (marketing capabilities), is crucial. As regards drawing an appropriate sample, he recommended:

Include:

(1) the ten largest (key) companies e.g. IBM, Canadian Marconi, Northern Telecom.

(2) Two or three software companies.

(3) A few manufacturing companies.

(4) A few "start-up" situations in software, engineering, or consulting.

In his view, very few people need to know higher level mathematics - for the vast majority what was needed was a "hands-on real-life math capability". The value of education lies in the thinking processes it can develop in the hands of a good teacher. A set of 12 issues of the Hi-Tech Review published by his company was obtained for reference.

5. The Relationship of the Project to Education and The Curriculum

In designing the project, the investigator also tried to keep in mind the ultimate use of the findings i.e. their value in improving learning, expecially in school mathematics, in an age of high technology. In the development of the instruments to be used, he therefore developed background files based on his general view that the mathematics curriculum and learning experiences are still greatly separated from other subject areas and from the industrial and business enterprise of society and local communities. Some of the areas which potentially might contribute to these instruments as they were developed and refined over time are the following:

The Relationship Between Mathematics and Computer Science
The Place of Logic and Intuition
The need for integrating Mathematics across the School Curriculum
Measurement, Design, and Problem Solving as significant foci in learning Mathematics

In connection with these perspectives, the investigator made visits in April 1984 to Gompers Secondary School, San Diego, California, one of the so-called "magnet schools" associated with the reform of science education in the USA, and to Peopleware Systems International, a California consulting firm involved with an exciting project in futures curriculum development, aimed at a

curriculum which would focus on information management skills (Quinn and others, 1983).

The magnet school in San Diego featured an interesting set of courses from grades 7 through 12. Included in these were computer courses, science courses, and for example, in grade 7, an interesting science course focussing on measurement which included work and exercises involving decimals and approximations so that maths and science were well integrated in the course.

In early 1984, the futures curriculum project was nearing the end of Phase II (Curriculum Development Phase) of a five-year five-phase process. Six futures curriculum diciplines had been selected, "with four having priority: Information Technology; Strategic Reasoning; Artificial Intelligence: Robotics; and Change. The two remaining areas to be developed are Life Planning Skills and Human Relations, the last considered a correlate of the country's increasingly pervasive transformation to a service economy." (Ibid, P. 38). The investigator was able to obtain relevant information about the general plan of the Project, including the fact that the Edmonton Public Schools is one of the 11 members of the cooperating network. It is hoped that in designing an expanded research study that the experiences gained in the development of this project since then can be taken into account.

Brief Summary of Phase I

Work on Phase I ended in May, 1984, as the investigator was due to have surgery in early June, and after recovery, to leave for Australia on Sabbatical Leave by late July, 1984.

At this stage, it was felt that considerable progress had been made in a number of areas.

1. Contact had been established with relevant national associations such as EEMAC, CATA and CBEMA, views had been obtained about the study from these and numerous other sources, especially federal and business ones, and an initial list of 12 hi-tech areas developed.

2. Background material on the scope and structure of mathematics itself, and the process taxonomy (expected to be a central feature of the study) had been developed to a usable level.

3. A model for the design and implementation of the study had been developed, and relevant source material either sought or obtained in connection with both the choice of "enterprises" to be included in the sample, and the procedures which might be employed.

4. A tentative choice of Northern Telecom, Belleville, as the object and site of the pilot study had been made.

PHASE II AUGUST 1985 - JUNE 1986

On his return from Sabbatical Leave, the investigator faced the task of obtaining the services of another research assistant. He was very fortunate in securing the cooperation of Bryan Scholes, a local computer consultant, whose undergraduate degree was in engineering, and who had worked as a High School Mathematics teacher for five years before deciding to go into business himself. Bryan's experience and knowledge proved invaluable both colleagrally and as a sounding board for the remainder of the project, principally until February, 1986.

Two major activities occupied the Fall of 1985 and early 1986:

(i) The planning and carrying out of the pilot study at Northern Telecom in Belleville;

(ii) The further development of an appropriate meaning for high-technology as a way of identifying the population and hence the sample.

The Pilot Study

From mid-August through mid-November, the investigator concentrated strongly on the pilot study, spending five or six full days in Belleville in late August getting it underway, and an average of once a week until mid-October conducting interviews

there. This was interspersed with the design of further questionnaires and interview instruments.

The actual interviews were conducted during the period August 23 through October 11, 1985. Forty employees in all were interviewed, from eight areas of operations, and four levels of vertical structure. The reader is referred to Appendix IV for a full account of the study, which was compiled by the investigator in early 1986 in order to obtain feedback and comments from Northern Telecom, as to its acceptability and possible inprovements.

In particular, attention is directed towards the four instruments used, the results of the study, and the valuable feedback comments received, and discussion of the implications for an expanded study. The most significant results, in the view of the investigator, were:

(i) All employees confirmed that they were using planning and thinking activities, strategies and processes matching these identified in the process taxonomy (Appendix VI, Page 30).

(ii) The significant use of the computer to access and retrieve data and, at higher levels of responsibility, as a design, production and control tool.

(iii) The central importance accorded to"percentage" as a topic in the curriculum .

Operational Definition of "High Technology"

The work carried out in Phase I ending in the completion of a list of 12 likely area comprising "hi-tech" was continued in the Fall of 1985. Two activities made up the thrust of further development of a definition. Firstly, discussion of the focus of the study resulted in further visits, especially to specialists in high technology, financial analysts, and government organizations. This led to a wider view of high-technology, as meaning the creation and use of advanced technology not only in manufacturing but also in areas such as consulting, service industries, such as health, banking and travel, and government departments or support structures. The second activity was the development of a tentative 7X3 matrix comprised of 7 categories deemed to be hi-tech against three sizes of organization as a first attempt at a 'population sample" space.

The development has been written up separately as Appendix IV, which should be consulted for further details. It led finally to the following list of eight major areas which are probably acceptable as a population from which to draw on in an expanded study.

Communications

Software (Systems) including artificial intelligence

Advanced or new materials

Advanced manufacturing technology (Robotics, CAD/CAM, CIM)

Optoelectronics (Laser, Video)

Hardware (Systems)

Applications (Health, Office, Travel, Banking, Education)

Biotechnology

Other Activities

Other activities of relevance to the study during Phase II included attendance at a one-day seminar on Office Automation in November 1985, and at four conferences in 1986.

The November seminar was entitled Today's Workstation: Making Intelligence Work For You. It was sponsored by the Canadian Information Processing Society and provided valuable insights into how various technologies such as local area networking (LAN) were converging together to change work processes. Several excellent contacts were also made. The holding of the seminar coincided with an official Toronto Globe and Mail Report on The Office and Computers which reinforced the trends outlined in the seminar. In particular, it contained excellent articles on IBM Canada and the Canadian Business Equipment Manufacturers Association (CBEMA) outlining how they have been moving towards automating the office and making it "the centre of new ideas and creativity".

At the Fifth Canadian Symposium on Instructional Technology in Ottawa on May 1986, the theme was "Computer-Assisted Learning - The Next Five Years". The central issue identified by the keynote speaker was the need to develop a good model of human learning so that the quality of software would be improved. Other areas relating to the theme of the research study were

industrial training and artificial intelligence. Again, several useful contacts were made, particularly with people in the field of industrial training (Crawford, 1986).

Finally, the investigator participated in a workshop-type conference in early June 1986 - the 10th annual Conference of the Canadian Mathematics Education Study Group. He was a member of the group studying the theme "The Role of the Microcomputer in Developing Statistical Thinking". With the continuing increase in the significance of biotechnology, it is likely that greater emphasis and understanding will be needed in the area of statistical thinking. This group is hoping to continue its work over the next year or two, and perhaps develop some appropriate software.

As noted in Appendix IV, files on various areas of hi-tech have also been developed and maintained. These include materials on (i) CAD/CAM, Robotics, Expert Systems, and Computer Integrated Manufacturing (CIM), and (ii) Biotechnology, including material relating to new products and to the National Advisory Committee Report of November, 1985. The magazine High Technology is particularly useful as a source for one to keep informed about high-tech trends and developments in numerous areas.

SUMMARY AND CONCLUSIONS

This feasibility study commenced operationally in August 1983, and after an intervening period of inactivity due to illness and sabbatical leave (from June 1984 through July

1985),concluded in June 1986.

Phase I of the study was essentally a thinking and planning period. Discussions were held, important sources of material and data found, and useful contacts for further consultation established. Significant progress was made in identifying a "hi-tech" population, and in developing a usable taxonomy of mathematical processes.

Phase II was much more active. Its major focus was the field study in Belleville. This saw the development of further instruments principally a content questionnaire, but also two further taxonomies for potential use, one on objectives in mathematics and the other on desirable employee skills. The actual interviewing was begun under pressure as the regulations covering SSHRC grants were undergoing change and the investigator was initially expecting to complete the study by early 1986 in order to make application in March 1986 for a further major grant. However, this pressure brought a very valuable lesson as it highlighted the considerable time needed for adequate preparation to undertake such a study. The investigator decided in September, after consultation with officials in SSHRC to forego a hurried attempt to conclude the study instead, and obtained a further extension for the feasibility study.

The results of the pilot study, particularly the success of the process taxonomy, and the need to streamline the time needed by respondents to complete questionnaires, were extremely important outcomes for the investigator. Clearly, preliminary

liaison with appropriate representatives of any cooperating firm or organization is vitally important in order to assess realistically the basis and extent of interviews and responses and the amount of time involved.

The very considerable effort expanded on clarifying an appropriate meaning for hi-tech may in retrospect have been excessive, yet brought valuable interaction with specialists in various areas and has enabled the investigator to see the meaning of this new advanced technology age in much better perspective and develop tentative criteria for choosing the population and sample. Thus, a more manageable project of a predominantly case-study nature seems to be emerging as the vehicle for an expanded study.

Finally, the significance of the computer and its associated discipline, computer science, as they relate to productive enterprise and school curricula have been clearly demonstrated, and need to be included consciously as part of the design of any further study.

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APPENDIX I

MATERIALS USED IN

VISITS AND DISCUSSIONS

The Mathematics Curriculum and the Use of Mathematical Knowledge and Skills in Canada in an Era of High Technology

Principal Investigator
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Kingston,
Ontario

A Research Project funded by the Social Science and Humanities Research Council of Canada

July 1983

Summary of Project (Oct 82)

The basic aim of the project is to identify, examine, and analyse competencies and skills needed in significant areas of Canadian industry and business with a view to assessing their implications for the teaching and learning of mathematics in schools and elsewhere. In the first instance, the focus will be on high technology industries, specifically in the areas of microelectronics, and biotechnology, with a possibility of including the petro chemical industry. A secondary aim is to examine the mathematics used in adult life both in citizenship and for leisure purposes as the high technology era becomes more dominant.

The first stage, which will be exploratory and organisational, will consist of contacting various Federal Government Departments, organisations and individuals e.g., Manpower Training and Immigration, Science Council of Canada to ascertain what relevant work is in progress, (e.g., The Science Council has several publications on implications of high technology as well as an on-going Science Education project, while Manpower Training and Immigration is conducting revision of current occupational categories in a project called Job Scan) Contact will be also made with the Canadian Manufacturers' Association, and the more specialised Canadian Electrical and Electronic Professional Organisation, as well as with individuals and grops working in the technology fields being studied

As a result of this phase, a small number of firms and organisations will be selected for an indepth study. It is possible that a small Advisory Committee may be formed at this stage to assist in the further conduct of the project. This device has proved useful in two previous research projects with political implications in which the author was involved.

If a grant is obtained, it is expected that this first phase will begin in Summer 1983. An application is also being made for some seed money (about $1500 internally at Queen's University to assist in making some of these preliminary contacts and screening so that the time for Phase I is seen as approximately 3 or 4 months at most.

Phase II, hopefully beginning in October 1983, will consist of a limited number of indepth studies of selected firms and organisations (maximum 8 to 10). The main vehicle will be personal visits, and interviews, structured and refined on the basis of Phase I, supplemented by the examination and analysis of relevant documents, reports, technical specifications, job descriptions etc.,. This will be supplemented by telephone interviews as required, and possibly by a survey questionnaire.

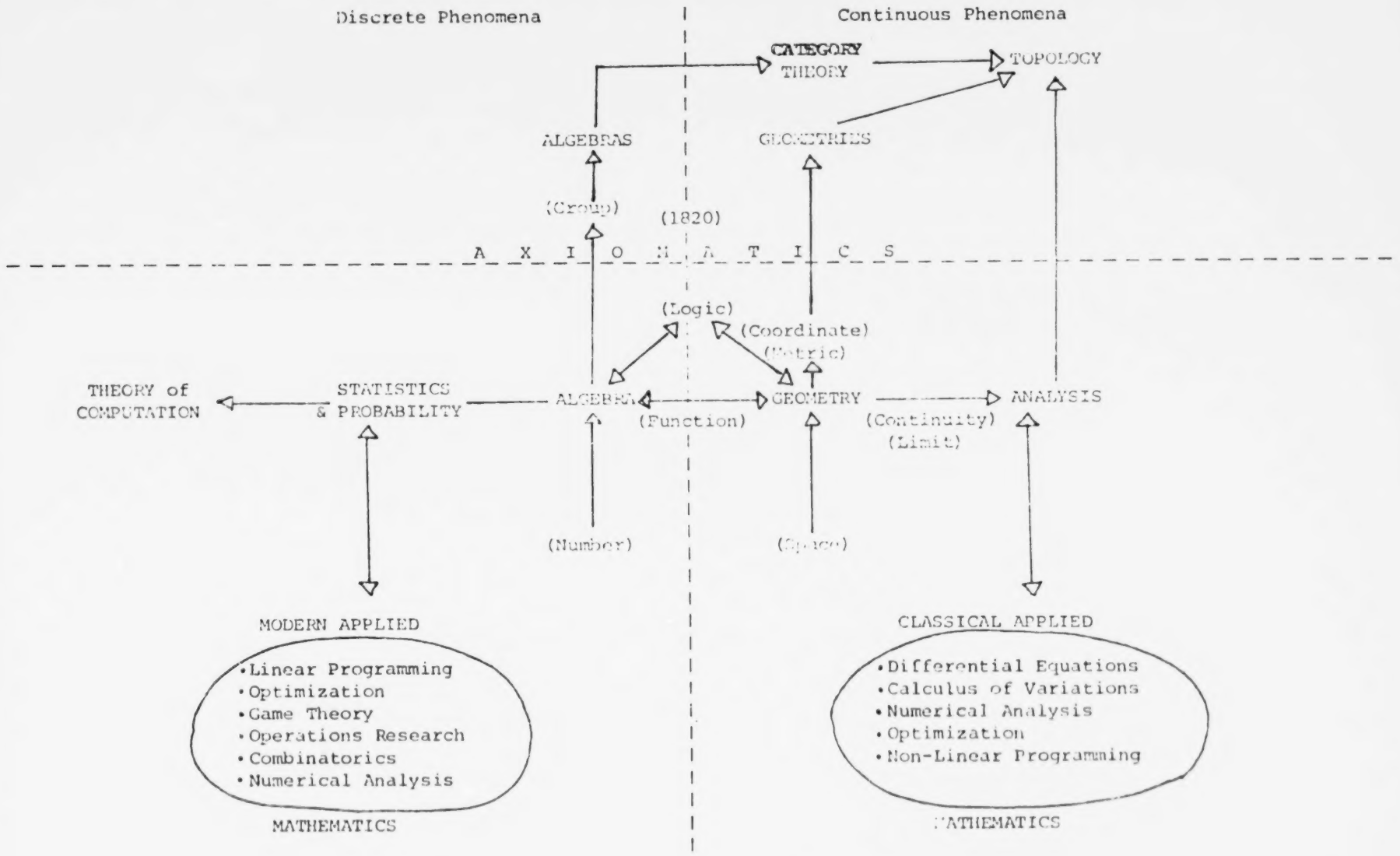
Since the project is envisioned initially as being of a pilot nature, it is intended that quality rather than quantity be the criterion so that the project remains manageable as to time demands and pressures. It is hoped to use some form of the following conceptual framework in conjunction with Smith and Varteniuk's earlier work in generic skills to categorise the skills being identified. This scheme wil be refined during Phase I.

Levels of Mathematical Needs

Level	A. People	B. Business and Industry
1	Adult citizens needing mathematics for daily living and citizenship	Basic for all business and industry
2	Technicians and craftsmen, requiring lower restricted mathematical skills	Needed for departments common to a business (e.g., Finance Office)
3	Professionals needing substantial mathematical knowledge in professions involving mathematics,	Common to sub-sets of industry
4	Specialists taking University Mathematics degrees	Unique to a particular industry

It is hoped to conclude Phase II by the summer of 1984. The project, if successful, can be extended in a more systematic way to address wider aspects of industry and business, and the large question of adult citizenship needs. A separate proposal is envisaged for conducting such an extended study.

AREAS AND CONCEPTS OF MATHEMATICS AND THEIR RELATIONSHIPS



c. D.H.Crawford,
first draft,14/10
1983

A TAXONOMY OF MATHEMATICAL ACTIONS AND/OR ACTIVITIES PROCESSES

© DOUGLAS H. CRAWFORD, AUGUST 1983

LEVEL AND GENERAL DESCRIPTION	ACTIVITY/PROCESS
A. Individual - Building blocks for major mathematical activities	
1. BASIC - Activities initially at a concrete manipulative level to establish sets, matchings, correspondences and relationships.	Classify, sort, associate, relate, order, transform. Combine, unite separate, undo generate. Describe, symbolize interpret. Represent.
2. HIGHER ORDER - Activities/processes which depend on the "internalised activities" defined as basic.	Establish patterns Formulate rules
	Conjecture, hypothesize, guess, test, verify, reject.
	Demonstrate, explain, justify, Make logical inferences.
	Abstract, structure, Analyse Data, Reverse, Re-structure direction of thought.
	Generalise, extend, specialize, shorten, curtail, systematize, make precise.
	Represent, model.

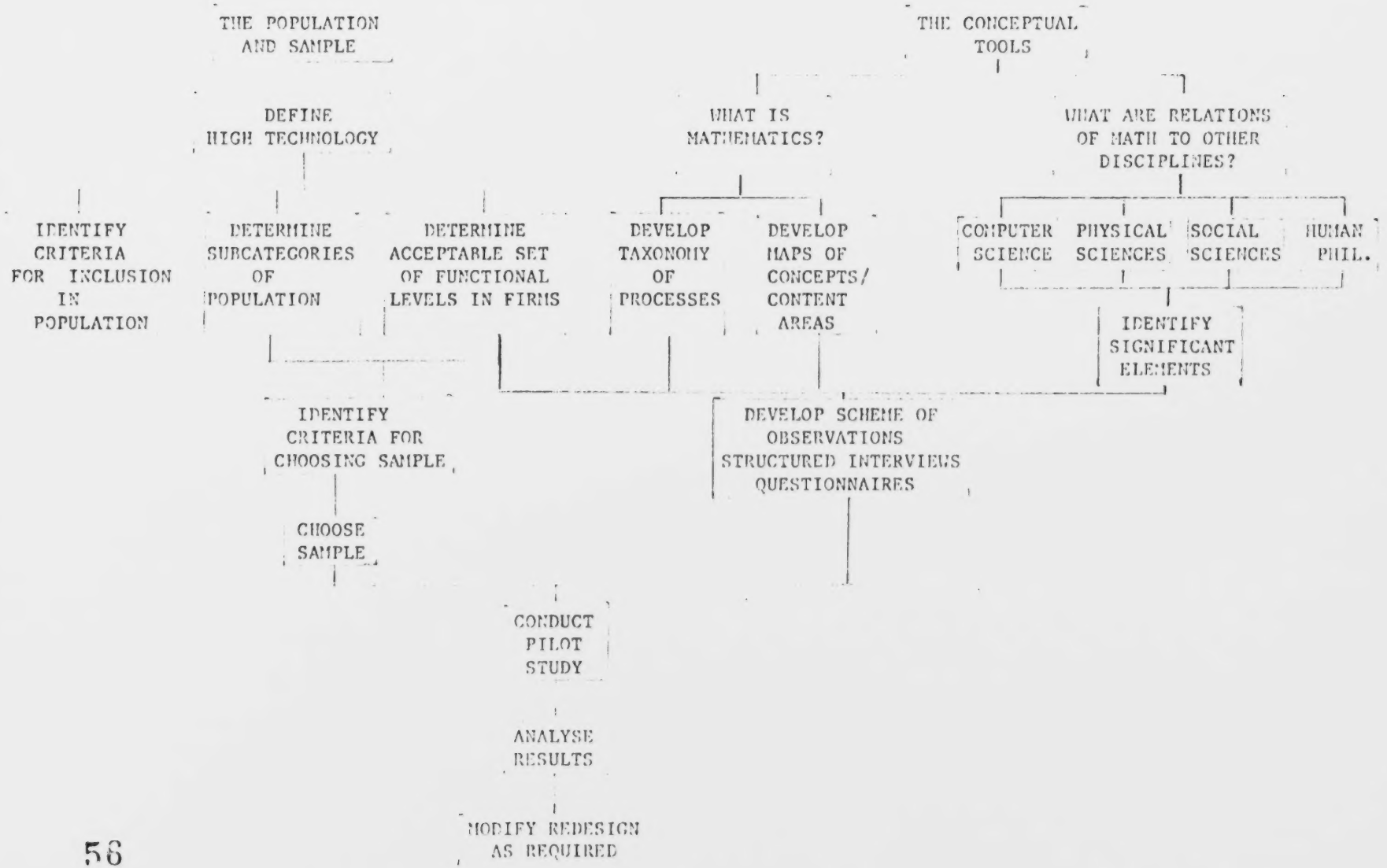
B. COMPOSITE, GROUP, COMPLETE - These are major complete mathematical activities composed of individual and higher order building blocks.

1. PROBLEM-SOLVING - Most natural purposeful mathematical activity, encompassing the use of low level simple processes, concepts and skills to very high level ones.	i) Assimilate goal and identify data. ii) Search forward for implications of data. Search backwards for pre-implications of conclusions. iii) Make connection for complete chain between data and conclusion by finding some correspondence. iv) Verify by working through and testing links, connections, and plausibility of conclusion. Overrule use of productive and reflective modes of operation sequentially and optimally.
2. PROOF - Activities which lead to the conviction by logic of the truth of some statement, or hypothesis e.g. theorm in geometry. Deeper levels develop beginning from partial rational conviction, (subjective) to total rational conviction (objective) to sophisticated levels of elegant deduction.	Search forward and backward for evidence to link data and hypothesized truth. Make inferences to this end. Processes are similar to those for problem solving.
3. MATHEMATISATION - This activity brings together into one whole the processes of abstraction, generalization and representation. It includes also the process of mathematical modelling which is basic to solving many problems in applied mathematics.	i) Recognise some structural aspect of a situation and abstract important variables and their interrelationships. ii) Represent those aspects by means of a diagram, a symbolic expression or some other form of analogy. iii) Generalise the structural property by verification of necessary and sufficient conditior or Model the situation by changing variable(s) in the representation to study the consequences. iv) Justify the generalization or model by testing and asking appropriate questions.

APPENDIX II

THE DESIGN OF THE STUDY

THE DESIGN OF THE STUDY


THE POPULATION AND SAMPLE
THE CONCEPTUAL TOOLS
DEFINE HIGH TECHNOLOGY
WHAT IS MATHEMATICS?
WHAT ARE RELATIONS OF MATH TO OTHER DISCIPLINES?
IDENTIFY CRITERIA FOR INCLUSION IN POPULATION
DETERMINE SUBCATEGORIES OF POPULATION
DETERMINE ACCEPTABLE SET OF FUNCTIONAL LEVELS IN FIRMS
DEVELOP TAXONOMY OF PROCESSES
DEVELOP MAPS OF CONCEPTS/ CONTENT AREAS
COMPUTER SCIENCE
PHYSICAL SCIENCES
SOCIAL SCIENCES
HUMAN PHIL.
IDENTIFY SIGNIFICANT ELEMENTS
IDENTIFY CRITERIA FOR CHOOSING SAMPLE
DEVELOP SCHEME OF OBSERVATIONS STRUCTURED INTERVIEWS QUESTIONNAIRES
CHOOSE SAMPLE
CONDUCT PILOT STUDY
ANALYSE RESULTS
MODIFY REDESIGN AS REQUIRED

D. H. CRAWFORD
MAY 1984

APPENDIX III

A TAXONOMY OF ACTIVITIES, PROCESSES AND SKILLS IN MATHEMATICS

A TAXONOMY OF PROCESS ABILITIES AND SKILLS IN MATHEMATICS

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A paper prepared in connection with a short oral communication delivered at the Fifth International Congress on Mathematical Education, Adelaide, South Australia.
August 24-30, 1984

ORIGIN OF THE TAXONOMY

In the fall of 1982, the author made a research proposal to the Social Science and Humanities Council of Canada (Crawford, 1982). He received funding from the council in the Fall of 1983 to carry out a 1-year pilot study of the project. The basic aim of the project is to identify, examine, and analyse competencies and skills needed in significant areas of Canadian industry and business with a view to assessing their implications for the teaching and learning of mathematics in schools and elsewhere. In the first instance, the focus is on high technology industries, particularly in the area of microelectronics. The general approach will be to make observations, conduct interviews, and use questionnaires in a survey of hi-tech firms and other related organizations and individuals in order to gain a valid and reliable map of how mathematics is used in such industries.

Having available a taxonomy of mathematical activities and processes was seen by the author as a necessary conceptual resource and tool, which he would use in conjunction with other conceptual tools as a means of carrying out the observations, interviews etc. effectively. i.e., the taxonomy is seen as a means to an end, and hence as a working guide and resource rather than a precise or perfect instrument.

SOME FACTORS AFFECTING THE TAXONOMY

In developing a taxonomy of processes used in mathematics, the approach taken here has been essentially empirical, and

instrumental. Thus little time has been spent trying to sort out precise meanings for terms such as 'activities', 'processes', 'abilities', 'skills', 'strategies', etc. An activity or process seems to be any kind of dynamic human event, whether physical or mental; a skill, according to Bell (1977) is a learnt routine; and an ability is a capability or competence to carry out some task or set of tasks. In retrospect, the taxonomy constructed might best be called one of processes, as this term seems to avoid some of the pitfalls inherent in possible confusion between on-going activities and the products (abilities, skills) which may be the results of these processes.

Apart from terminology, several other factors complicate the possiblity of a simple taxonomy. One of these is the time dimension, both short term, i.e., the way processes are juxtaposed or used together in doing mathematics, and long-term i.e., the order or sequence in which processes and schema (to use Skemp's term) become available to students to use in their mental functionings. Thus in interpreting the taxonomy, the level of functioning - physical, visual, or abstract - will play a considerable part. It seems well established that concepts are what Piaget calls "internalised actions", and that the degree and clarity of understanding and using the concept depend on the variety and level of experiences engaged in as the concept is formed. As regards the long-term, Piaget has suggested that as they grow children pass through in sequence, at least three cognitive stages of development (i) pre-operational (ii) concrete operational and (iii) formal operational. Dienes (1959) comments

as follows:

> The critical ages of passing from one stage to the next appear to occur at seven and twelve years of age. In the stage up to seven, play is predominant as a cognitive process, in other words the child is unaware of the fact that he is learning. Between seven and twelve comes so-called concrete operational stage, where the child is aware of the learning situation and learns from his own concrete experiences. After twelve, he is able to assess these concrete experiences, put them into classes, and he is able to think in terms of the relationships of these classes. In other words he makes use of the concrete experiences collected in the previous stage. This is known as the logical stage, the consideration of relationships between classes being the essence of logical thought.

Finally, mathematics can be viewed either as pure or applied mathematics. Sometimes, a student will be involved learning mathematical techniques and ideas totally within the structure of established mathematics, e.g., solving quadratic equations. At other times, however, he needs the ability to move between situations and problems which are occurring in the real world, but which are best solved by translating them into mathematical terms, solving them mathematically, and then interpreting the

results back in the real world. In such cases, the student is doing applied mathematics.

In attempting to interpret the taxonomy which the author has developed, these factors should be borne in mind as part of the complex context in which such processes always take place.

DEVELOPMENT OF THE TAXONOMY

The first stage of development comprised a study of sources which focussed on processes used in doing mathematics and judged significant by the author. Among these were Morley (1969, 1973) Scandura (1971), Wheeler (1975), Romberg and Montgomery (1976), Bell (1977, 1978) Fielker (A.T.M. 1982) and Mason (1978). This yielded an initial list of processes (Figure 1) which was then used together with other sources on problem-solving, mathematical modelling, and mathematization (Polya (1965), Ford and Hall (1970), Bishop (1971), Wheeler (1975), Crawford (1976) and Mathematical Association of of America (1981)) to produce a tentative first draft of the taxonomy. There were three main features of this (Figure 2)

(i) a set of basic activities at the concrete or manipulative level,

(ii) a second set of processes which were classified as internalised actions, although no real attempt was made to put these in any sequential order,

(iii) three more composite or complete mathematical processes - problem-solving,

> proving, and mathematizing which seemed to bring together into some form of completeness, several of the individual mental processes already listed such as conjecturing, explaining, abstracting or generalising.

Little change was made in the first draft for several months, although it was shown to a few individuals whose reactions varied from relative indifference, to general agreement with it.

Finally, some time was spent in April and May 1984 with a school system coordinator and long time colleague of the author with long and thoughtful experience at all grade levels from K through 8 and with David Wheeler, of Concordia University the well-known mathematics educator, whose particular interest in the concept of mathematisation is well known. As a result of these discussions and further study of the literature, the current form of the taxonomy has been reached.

It is the author's intention, during his current sabbatical leave, to obtain more systematic reaction to the taxonomy from practising teachers, mathematical educators, university mathematicians, individual mathematicians and educational psychologists, and so improve it considerably.

SIMPLER ASPECTS OF THE TAXONOMY

In reviewing the first draft, it seemed that the various lower order activities and processes might be grouped sequentially, and then would fit together fairly naturally with

the composite ones already identified, i.e., problem-solving, proving and mathematizing. This review resulted in Part I of the revised taxonomy which is shown in Figure 3. The processes involved have been summarized into six which operate sequentially, namely compare and relate; abstract; represent; explore, transform and deduce (re-structure); justify and explain; interpret and communicate. This set of processes is seen as operating at the pre-school and elementary level, well exemplified in projects such as The Nuffield Mathematics Project, (Matthews and others, 1964 on) and the Individually Guided Mathematics Program (Romberg and others, 1976).

MATHEMATICAL MODELLING

In the months after putting together the first draft, the author spent a fair amount of time examining literature on mathematical modelling. This feature of doing mathematics has gained considerable prominence, particulary at the University level, since the beginning of the 1970's when it was mentioned by Ford and Hall (1970), Bishop (1971), Griffiths and Howson (1974) and numerous others, particularly in the journals The International Journal of Mathematics, Science and Technology and The American Mathematical Monthly. Its importance is underlined by the following statement in the C.U.P.M. 1981 Report:

> The creation of new knowledge via this modeling route is at the heart of theoretical science and applied mathematics. (CUPM Report, p.74)

Various authors describe the process in different language

(Ford and Hall (1970), Crawford (1976), Wann and Woodrow (1980), CUPM Report (1981), Berry and O'Shea (1983). Basically, there seem to be 4 phases, as indicated in Figure 4, which is adapted from the CUPM Report. The table below the diagram of the process, shows the four phases, together with comments, while the main primary mathematical and "meta-mathematical" processes which seem to be involved at each stage are given at the right.

It should also be noted that Bell in his 1978 paper seems to restrict the modelling process to "the representation of some situation via a diagram, a symbolic expression, or some other form of analogy." Nonetheless, all mathematics educators including Bell who have studied modelling and its implications for the mathematics curriculum agree on its significance for giving the pupil and more genuine experience of mathematical activity. Finally, it is worth noting that modelling cannot and does not begin until there exists a problem to be modelled.

MATHEMATIZING

This word seems to have entered the vocabulary of mathematics education in the 1970's. Wheeler (1975) suggests that although a substantial step towards demonstrating that mathematics is a human activity was made by substituting the goal of facilitating children's mathematical activity for that of passing on mathematical knowledge, we are still dominated by focussing on producing "recognisably familiar mathematics." He introduces the word "mathematization" as a label for the process of mathematical activity and argues that we may be able to liberate mathematics

from being judged only by its past products since in his view children have the necessary (physical and mental) functionings to mathematise independently of mathematics as we know it. He develops this theme in later writings (Wheeler, 1980, 1982). Among the ingredients of mathematization, Wheeler includes

i) perceiving relationships and transforming them into new ones mentally

ii) internalising actions or perceptions in order to make conjectures

iii) capacity to coordinate and contrast the real and the ideal and to synthesize the systems of perception, imagery, language and symbolism

(adapted from Wheeler, 1975)

In his 1980 and 1982 writings, Wheeler expands on the ability to mathematize. Thus by acquiring spoken language and developing visual perception, pre-school age children show their ability to mathematize as they can "perform mental operations such as classification, transformation, substitution, and reversal." Wheeler sees mathematisation as being "detected most easily in situations where something not obviously mathematical is being converted into something that obviously is." Evidence of its taking place are when signs of organisation, of form, of additional structure are given to a situation. He offers three kinds of mental actions which he finds in many examples of mathematical thinking as characteristic of mathematising

(i) <u>making distinctions</u> - underlies

constructing mathematical sets and relations

(ii) <u>extrapolating and iterating</u> - producing new things from old ones

(iii) <u>generating equivalence through transformation</u> - generating stability out of flux

Finally, in personal discussion in May 1984, he commented that mathematising is or can be "more spontaneous than modelling or problem-solving, in that a situation triggers off the recognition of some problem to be solved."

Bell (1978) in his section on mathematisation says that it "embraces the processes of abstraction, generalisation and representation." He includes in this section a discussion of modelling and symbolisation as well as a list of mathemtical abilities developed by Krutetskii (1976) in his research studies.

He cites Freudenthal, who

> "describes mathematical activity as the organisation of a field by mathematising, that is by forming spatial or numerical or other relational concepts within it and by structuring it by logical relations. Abstraction, generalisation and representation by symbols and other models all form a part of this activity." Bell (1978, p. 49)

PROBLEM-SOLVING

Problem-solving is the process aspect of mathematics which received earliest systematic attention. Thus Polya in a series of books beginning with How To Solve It (1965) enunciated various approaches and strategies for solving problems, perhaps the most well known and effective being to try to solve a simpler but similar problem, and then extrapolate or generalise. Bell (1978) described four phases - assimilation, exploration, insight or illumination, and verification, which were incorporated in the first draft of the taxonomy. Similar suggestions are made or implied in the NCTM 1980 publication Agenda for Action.

Bell and colleagues (1983) discuss problem-solving research and its implications in great detail, with a view to better improving its learning, as a major goal of school mathematics for the 1980s. They cite a recent study by Treilibs and other (1979) entitled "Formulation Processes of Mathematical Modelling" which explored the importance of aspects of mathematical modelling for real problem-solving. No real details were given, and so the importance of this study for the present taxonomy is unclear, pending a study of the original research.

Problem-solving must be distinguished from problem formulation, as the process of solving seems to imply that some problem has been presented or is available for solution. This is recognised by Bell and colleagues (1983) in their decision to widen the domain of doing mathematics to include the process of investigation of which mathematical investigation, according to them, is a subset. The implications of this for the taxonomy

will be discussed later.

Finally, solving a problem does not necessarily imply that rigorous mathematical proof has been employed. One may obtain a solution to a problem by non-rigorous means, e.g., guessing or trial and error, and provided the solution is acceptable for the solver, such problem-solving processes may well be considered adequate.

PROVING

Proving is often thought of as the central activity of doing mathematics. Like other aspects of mathematics, it is a concept which develops in rigour with increasing age - from "being convinced" by external authority, to the stage at which it implies the construction of a set of logically related statements forming an unbroken claim from some beginning statement to some conclusion. The logical process involved is then called proving. The underlying processes which finally yield the claim of logical reasoning are similar to those used in solving problems, in mathematising, and in modelling. Bell and colleagues (1983) also refer to proof in the sense of constructing a deductive system. According to a recent study of proof by Hanna (1983), in mathematical practice, "rigorous proof is secondary in the eyes of practising mathematicians to understanding and significance."

REVISION OF PART B OF THE DRAFT VERSION

The draft version of the composite processes was modified slightly by adding a section on mathematical modelling. This

amended version is shown as Figure 5.

RELATIONSHIPS BETWEEN HIGHER-ORDER MATHEMATICAL PROCESSES

So far, to the author's knowledge, no final agreed definitions of problem-solving, mathematical modelling, mathematising, or proving have evolved. In fact, it is doubtful if precise definitions are necessary or possible. It does seem desirable, however, to make the attempt to describe their characteristics as adequately as possible. In this way, some insight into their interrelationship can be gained, and hence some reference points can be found against which their significance in both applied and pure mathematics can be assessed, and hence suggestions and recommendations made for better teaching and learning of mathematics. Bell and his colleagues (1983) address this general area in their chapter headed Process Aspects of Mathematics.

The taxonomy, in summary form, is shown in Figure 6. Six "components" are shown. They are basic activities and processes, proving, problem-solving, mathematical modelling, mathematizing, and investigating situations. As indicated below, they tend to form a kind of hierarchy of processes involved in identifying and resolving problems found in real situations. Included also is an attempt to separate out which processes occur internally in the world of mathematics, which occur in the real world, and which are "transitional."

It may be helpful first to point out some other features of

interest of the taxonomy.

1. It is sequential vertically, i.e., relating, abstracting, etc. are processes which logically occur sequentially in time - though in fact many processes will be called into play in various sequences while a problem, or proof is being studied or constructed.
2. It is sequential horizontally, i.e., it attempts to describe composite mathematical processes as they have evolved and gained prominence historically. Thus proof appears historically before problem-solving, and mathematical modelling before mathematizing.
3. Those items in the taxonomy which have been positioned to be in the real world and not in the internal world of mathematics are being called activities since they bring into play complex interactions between the environment, and the physical and mental processes of the individual.
4. The taxonomy suggests a number of phases which comprise the total approach to a real world situation which is investigated mathematically. These might be described as:
   i) study, and investigate the situation
   ii) formulate a relevant real problem
   iii) internalise and represent it mathema-

tically

iv) solve it mathematically

v) interpret it in the real world

vi) decide what has to be done

vii) integrate the new knowledge and understanding with previous knowledge.

5. Altogether thirteen reasonably distinct phases of the start-to-finish process of moving from a real world situation to the resolution of a problem inherent in it and the accompanying integration mentally of the knowledge gained have been position.

USES OF THE TAXONOMY

Once the taxonomy has been further modified and validated empirically by discussions, comments, interviews etc. from relevant sources, it would appear to be potentially useful in a number of areas of mathematical education. Reference will be made briefly to curriculum development; evaluation and testing; and teacher education.

In developing the mathematics curriculum, a major criterion must be the purpose for which it is being created. Goals for school mathematics ebb and flow with changes and trends in specific societies. In the 1980's, in North America, problem-solving is clearly seen by most leaders as the major goal. In the U.K., the recent Report of the Cockcroft Committee (1982) concurred with this emphasis, when it stated "the ability to

solve problems is at the heart of mathematics." However, it continued

> ... the solution of a mathematical problem cannot begin until the problem has been translated into the appropriate mathematical terms. This first and essential step presents very great difficulties to many pupils - a fact which is often too little appreciated.

It then discussed the need to introduce investigational work as a way of making mathematics real, not simply a 'cut and dried' set of problems, proofs or exercises but an opening up of discussion and of willingness by the teacher to experiment when interesting questions arise. Wheeler (1982) sees mathematization as a key activity and purpose for school mathematics, while Bell and his colleagues seem to favour problem-solving as the main focus, yet give prominence to investigations as a major vehicle for this in their South Notts program.

> Mathematics provides the most readily accessible form of problem solving in the classroom because it does not depend on the pre-existence of a substantial body of knowledge. Involvement in problem-solving enables pupils to exercise and acquire confidence in their intellectual powers. Thinking independently and expressing arguments in a logical and ordered manner does not always come easily. Good habits can be

> acquired by being in an environment in which thinking is explicitly valued, and by coming to recognise the general value of reasoning. One may also acquire some strategies which are more generally useful.

The value of the taxonomy for curriculum development seems to lie in its identifying the relationships between the various phases which make up the overall activity called mathematics. But it still leaves open the actual content, and body of actual concepts and relationships which at any time make up the mathematical resources and data on which a student can call in solving further problems or investigating new situations. The taxonomy allows the curriculum developer or teacher to match particular processes which he values with particular concepts or problems which will require their use to solve. i.e., it is a general tool or resource to which he can refer and hence design the kinds of experience he wishes students to have. This is essentially what Programs such as the Stirling D.I.M.E. Booklets and the South Notts Project have done with considerable success.

In the area of testing and evaluation, the taxonomy could be used together with systems such as the SOLO taxonomy which offers a practical framework for classifying student outcomes on a qualitative basis. Recently in the USA, research and development supported by the National Institute of Education and the Educational Commission of the States have made use of the SOLO taxonomy to construct a set of problem-solving superitems to be used in the NAEP program to evaluate the quality of students'

mathematical problem-solving (Olive 1983). It is reasonable to suppose that the taxonomy could be used systematically with the SOLO taxonomy to assess the quality of student learning of most or even all of the processes identified in the taxonomy. Of course, the taxonomy could be used informally by a school Board, or by an individual school or teacher to evaluate student capability in specific processes or groups of processes.

Finally in teacher education, the taxonomy affords a framework which can be used to focus systematically on process aspects of mathematics. The author has already used the early draft of it together with study materials on abstraction and generalization; proving; and mathematization, modelling and problem-solving with student teachers intending to teach children in the Junior and Intermediate Grades in Ontario (4-10, ages 9 through 15). For this, he drew on many of the sources consulted in developing the taxonomy - in particular Bell and colleagues (1978), Giles (1972), Mason (1978), Crawford (1976) and Wheeler (1975).

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INITIAL LIST OF MATHEMATICAL ACTIONS, ACTIVITIES AND PROCESSES

SOURCE

	Scandura 1971	ATM 1973	Morley 1973	Romberg/ Montgomery 1976	APU/ (BELL) 1978	Bell 1978	Mason 1979	Christiansen 1981
ACTIONS ETC	Generalize Particularize Interpret Describe Make Logical Inferences Axiomatize	Classify Associate Order Transform Combine Undo Generate Describe Symbolize Hypothesize (Guess, test) Demonstrate Justify/Prove Extend/ Generalize	Classify Generalize Symbolize Prove Organize	Relate Represent Transform Validate Structure	Problem-Solving Proof Generalisation Investigation	Problem-Solving Proof Mathematization Modelling	Generalize Specialize Prove	Systematize Making Precise Generalising Specialising Establishing Patterns Formulating Roles Describing a Problem Describing a Method of Working Making a plan and carrying it out Having control over assumptions Reasoning from given assumptions

FIGURE 1

DRAFT VERSION OF COMPOSITE PROCESSES

B. COMPOSITE, GROUP, COMPLETE - These are major complete mathematical activities composed of individual and higher order building blocks.

1. PROBLEM-SOLVING - Most natural purposeful mathematical activity, encompassing the use of low level simple processes, concepts and skills to a very high level ones.

i) Assimilate goal and identify data.

ii) Search forward for implications of data. Search backwards for pre-implications of conclusions.

iii) Make connection for complete chain between data and conclusion by finding some correspondence.

iv) Verify by working through and testing links, connections, and plausibility of conclusion.

Overall use of productive and reflective modes of operation alternately and optimally.

2. PROOF - Activities which lead to the conviction by logic of the truth of some statement, or hypothesis e.g. theorm in geometry. Deeper levels develop, beginning from partial mutual conviction, (subjective) to total rational conviction (objective) to sophisticated levels of elegant deduction.

Search forward and backward for evidence to link data and hypothesized truth.
Make inferences to this end.
Processes are similar to those for problem solving.

3. MATHEMATISATION - This activity brings together into one whole the processes of abstraction, generalization and representation. It includes also the process of mathematical modelling which is basic to solving many problems in applied mathematics.

i) Recognise some structural aspect of a situation and abstract important variables and their interrelationships.

ii) Represent those aspects by means of a diagram, a symbolic expression or some other form of analogy.

iii) Generalise the structural property by verification of necessary and sufficient conditions.

or

Model the situation by changing variable(s) in the representation to study the consequences.

iv) Justify the generalization or model by testing and asking appropriate questions.

FIGURE 2

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A TAXONOMY OF ACTIVITIES AND PROCESSES INVOLVED IN DOING MATHEMATICS

PART I - LOWER ORDER PROCESSES

ACTIVITY/PROCESS	SINGLE WORD/PHRASE DESCRIPTOR	DESCRIPTION AND LEVEL OF OPERATION
Comparing/Contrasting Sorting, Classifying Relating	Compare and Relate	Basic activities engaged in at the concrete manipulative level resulting in the construction of correspondences, matchings, sets and relationships.
Abstracting	Abstract	These activities also result in the formation of basic concepts of number and space. Abstracting is a continuing central activity at all levels of mathematical activity.
Describing Representing Symbolizing	Represent	These are processes which are at the mental level; they may be mental, graphical or visual, or symbolic. They are processes which help to consolidate concepts already formed, and operate on them mentally in order to prepare them for being used mathematically.
Analyse data Generalise Conjecture/Hypothesize Transform Try-out, test Deduce/make logical inferences	Explore Transform and Deduce	These are processes in which data, concepts, and relationships are being analysed and explored in a creative way to gain insights by re-structuring in some way, e.g., extending, summarizing, interpolating, extrapolating.
Demonstrate Explain Justify Verify/Reject Validate	Justify and Explain	These are processes designed to consolidate re-structurings and advances made through use of the processes above, so that some final mathematical result or product is achieved, which is acceptable mathematically.
Interpret Communicate Report	Interpret and Communicate	These are processes which are meta-mathematical, i.e., the meaning of the mathematics is communicated in ordinary language in the real world.

FIGURE 3

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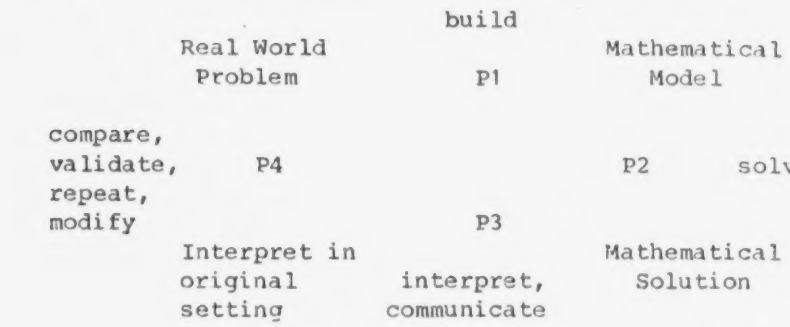
THE PROCESS OF MATHEMATICAL MODELLING



	Phase	Comments	Processes Used
1.	Build	most essential, creative	Abstract, Represent
2.	Solve	most emphasis is placed on this phase in teaching	Manipulate Transform Deduce Test
3.	Interpret	requires the ability to communicate precisely and clearly	Translate Communicate
4.	Compare	may involve experimenting, verifying, evaluating - two major criteria are simplicity and accuracy	Verify Validate Evaluate Decide

FIGURE 4

A TAXONOMY OF MATHEMATICAL ACTIVITIES AND PROCESSES

PART II - HIGHER ORDER PROCESSES

1. PROVING - Activities which lead to the conviction by logic of the truth of some statement, or hypothesis e.g., theorem in geometry. Deeper levels develop, beginning from partial mutual conviction, (subjective) to total rational conviction (objective) to sophisticated levels of elegant deduction.

   i) Search forward and backward for evidence to link data and hypothesized truth.
   ii) Make inferences to this end.
   iii) Complete chain of logically related statements
   iv) Validate

2. PROBLEM-SOLVING - Most natural purposeful mathematical activity, encompassing the use of low level simple processes, concepts and skills to very high level ones. Similar in many respects to proving.

   i) Assimilate goal and identify data.
   ii) Search forward for implications of data. Search backwards for pre-implications of conclusions.
   iii) Make connection for complete chain between data and conclusion by finding some correspondence.
   iv) Verify by working through and testing links, connections, and plausibility of conclusion.

   Overall use of productive and reflective modes of operation alternately and optimally.

3. MATHEMATICAL MODELLING - This activity lies at the heart of applied mathematics. It begins with the need for some identified problem to be solved mathematically and ends when an acceptable real world solution or resolution of the problem has been achieved. It can be thought of as occurring in four phases.

   i) Build Mathematical Model
   ii) Obtain Mathematical Solution
   iii) Interpret Solution in Real World
   iv) Compare this solution with original problem until (re) solution is achieved.

4. MATHEMATISATION - This activity brings together into one whole the processes of abstraction, generalization and representation. It includes also the process of mathematical modelling which is basic to solving many problems in applied mathematics.

   i) Recognise some structural aspect of a situation and abstract important variables and their interrelationships.
   ii) Represent those aspects by means of a diagram, a symbolic expression or some other form of analogy.
   iii) Generalise the structural property by verification of necessary and sufficient conditions.

   or

   Model the situation by changing variable(s) in the representation to study the consequences.

   iv) Justify the generalization or model by testing and asking appropriate questions.

FIGURE 5

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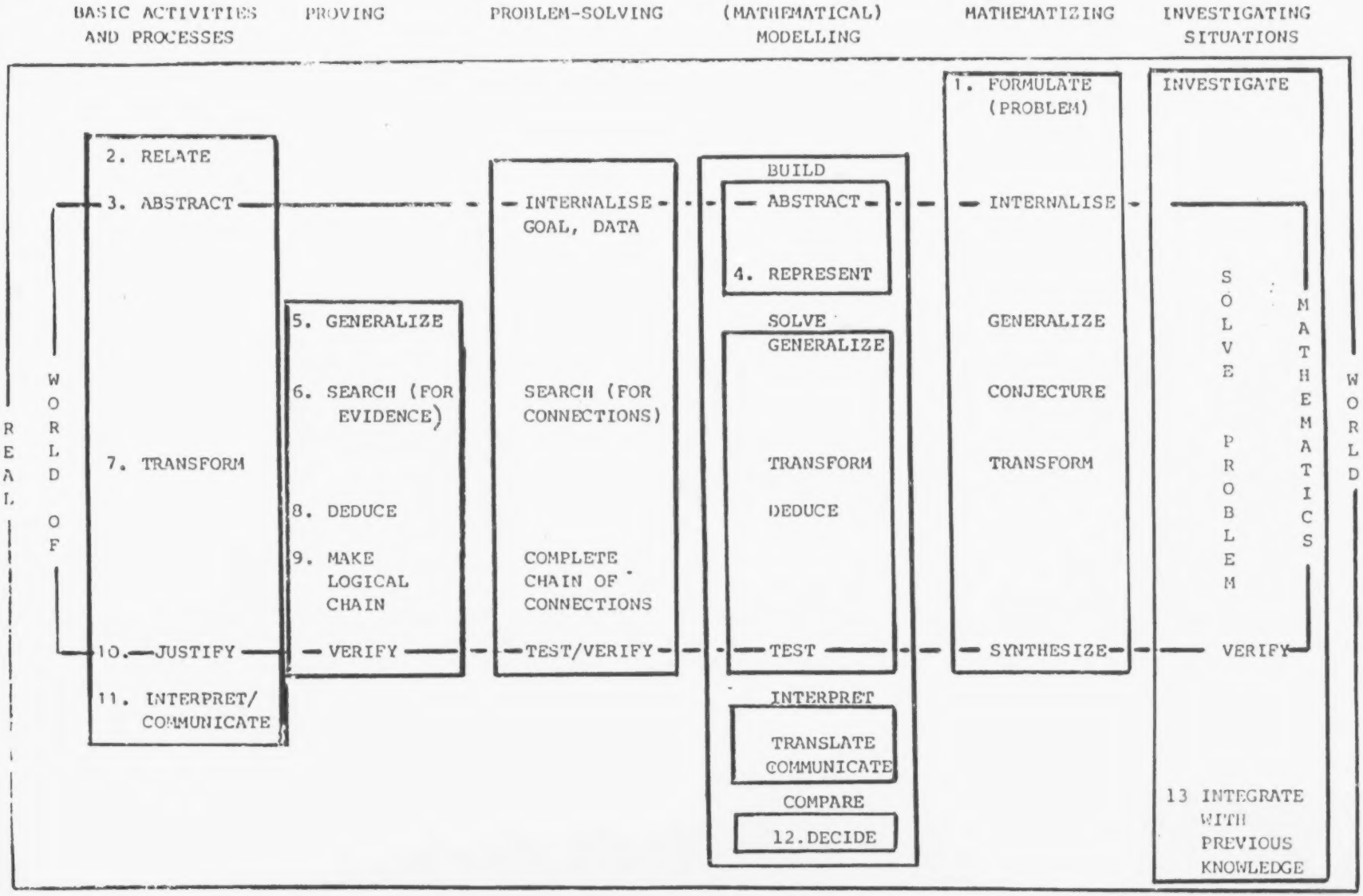
PART III - A SUMMARY OF BASIC AND HIGHER ORDERED PROCESSES



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APPENDIX IV

TOWARDS

AN OPERATIONAL DEFINITION

OF "HI-TECH"

FOR

RESEARCH PURPOSES

TOWARDS AN OPERATIONAL DEFINITION OF "HI-TECH" FOR RESEARCH PURPOSES

A

PAPER

PREPARED

BY

DOUGLAS H. CRAWFORD

IN

CONNECTION

WITH

A PILOT STUDY OF

THE IMPLICATIONS OF "HI-TECH" INDUSTRY

FOR THE SCHOOL MATHEMATICS CURRICULUM*

* RESEARCH FUNDED BY A GRANT FROM THE SOCIAL SCIENCES AND HUMANITIES RESEARCH COUNCIL OF CANADA

FEBRUARY, 1986

INTRODUCTION

Any research study which has as its focus high-technology industry, faces the problems of defining the term "hi-tech". Thus a primary pre-requisite for conducting the proposed research study is to have an acceptable operational definition of the term "hi-tech". Development towards such a definition occurred in two stages, the first up to the Summer of 1984, the second in the Fall of 1985.

STAGE ONE (1983-84)

1. Collection of Data

In 1984, a number of procedures were employed. These included visits to several professional associations (e.g. Electrical and Electronic Manufacturers Association of Canada (EEMAC), Canadian Advanced Technology Association (CATA)), federal government departments, and "hi-tech" firms (e.g. Mitel) as well as a search of a range of newspaper, financial and other reports. These yielded a considerable variety of documents and literature, in addition to the perceptions of the people consulted.

2. Significant Sources

Four sources, CATAlog in particular, yielded quite detailed lists of hi-tech areas: CATAlog (1983); the book High-Tech: How to Find and Profit from To-day's New Super Stocks; a set of area descriptions supplied by the Science Council of Canada; and a supply catalogue obtained from the Department of Supply and Services Canada. Additional information was obtained from various other sources, principally visits to professional associations, government departments, and 'hi-tech' firms. Major sources areWlisted in Attachment IA.

CATAlog is a sourcebook of bibliographical information about the member companies of the Canadian Advanced Technology Association. The data given in it were supplemented wherever possible using newspaper and financial reports from such publications as "High-Technology", the Toronto Globe & Mail, and the newsletters of investment analysts. The data and statistics for each company were then graphed for comparison on axes relating their product lines, annual sales, and age of the company. The comparisons were analyzed by product line, because the product determines the types of technology, materials, and manpower needed by each company. This resulted in a division of the CATA firms into seven areas, which in turn belonged to three very general groups: °Computer Systems and Software', °Medical and Scientific Equipment', and °Electronics and Communications'. The list is given in Attachment I B.)

The book High-Tech: How to Find and Profit from To-day's New

Super Stocks provides guidance for investors looking for opportunities in firms based on new technology. It uses a comprehensive checklist of factors for assessing any firm's potential for financial success. The author's 13 product-line categories were included in the initial list of classifications for consideration, and is also given in Attachment I B.

Three area-descriptions for high-tech industry received from the Science Council of Canada provided a similar listing of fields (see Appendix I B). Some initial entries were adjusted on the grounds that they were too specific and a more general but appropriate heading was used. To illustrate, the several specific applications of Recombinant DNA were put under the heading °Biotechnology and its applications'. Because the many materials listed by the Science Council are, as a whole, important to high-tech business a general heading °Materials' was chosen as one of the three major areas.

The fourth source was the Department of Supplies and Services Canada, which publishes the "Cataloguing Handbook H2-1". This booklet gives an exhaustive listing of all kinds of products, grouped into categories for government supply purposes. Those categories which implied high-tech production were used as a long initial list, then subdivided into areas in the same manner as CATAlog. This yielded the set of 9 areas given in Attachment I B. In addition, each of these areas so determined was cross-checked (with the products in each of CATA's categories) using a computer list of the specific products in each of the Supply and Services categories in order to make sure that when

the same heading was used in both it covered the same products.

Study from other files containing notes from interviews, company and corporate literature, and all kinds of articles (especially the excellent "Investments" and "Insights" columns from the magazine "High Technology") yielded support for many of the categories already selected. From these sources, Lasers, Robotics, and to some extent Fiber Optics stood out as representative of the leading edge of today's new technologies. However, no single one of these supplementary sources covered high-tech industry with sufficient breadth to use as part of the concensus on a shortlist.

As noted already, a bibliography of the sources consulted and from the lists derived from these are given in Attachments I A and B respectively.

3. An Initial Set of Hi-Tech Industry Areas

By this process 22 industry areas were identified. These were then used to compile the table given in Appendix II. This table was then analysed with the result that several categories were retained while several other initial categories were coalesced under slightly more general headings. Finally, this yielded the following set of 12 classifications (in no particular order):

- office automation
- computer hardware

- software and software development
- electronics (in general)
- avionics and military technology
- medical technology
- fiber optics, lasers, and microwaves
- communications
- biotechnology
- consumer products
- robotics
- materials

STAGE TWO (Fall 1985)

1. Further Issues and the Development of a Population Matrix

Conduct of the feasibility study was resumed late in July 1985, on the return of the principal investigator from sabbatical leave overseas. Further thinking, in particular discussions between him and his new research assistant, Bryan Scholes, raised several other issues relating to the objectives of the study, and the population which should be sampled. One of these was "To what extent should the study focus on the future as well as the present?" To allow for a future dimension, it seemed important that provision be made in the sample for small business firms in their early innovative stages of developing "high-technology". A second issue which arose was "To what extent should the focus of the study be on the creative phase

i.e., production of high-technology as opposed to the application of high-technology e.g., office automation. Could the 12 areas be reduced by classifying them in this way?" The question of what criteria might be used to identify hi-tech firms (e.g., R/D expenditures) also surfaced. In order to address these issues, it was decided to pay further visits to selected individuals; in particular, specialists in high technology, financial analysts, and government organisations directly involved with the meaning of °hi-tech' for policy, economic, or statistical purposes.

Also, in order to get some more specific idea of the intended population, and possible sample, two other avenues were explored. First, a list of individual firms, which would on face-value be considered as hi-tech, was compiled from 5 sources - two Toronto investment firms' stock exchange lists, the Toronto Globe and Mail Business 1000 Report for 1985, the CATA membership list and the Computer Systems Sources of the Ontario Ministry of Industry and Trade. This yielded a tentative list of 96 firms (see Attachment II). Secondly, a smaller list of 7 hi-tech categories was developed intuitively using the previous list of 12, and a list of 9 taken from the Toronto Globe and Mail Business 1000 Report for 1985. An "applications" category was included in the group of seven for the following reasons:

1) it seems to provide a bridge to the rest of the business world and society in general,
2) without it, the companies in the other groups tend to form a closed group with similar interests and

activities,

3) such a group that includes users of new technology rather than creators, will represent a larger number of people and reflect the impact of high technology on society as a whole.

Further refinement of the applications category is being considered; e.g., health and hospitals, tourist services, office automation.

Data obtained for 48 of the 96 firms identified above was used to classify them by size into 3 groups (up to 200 employees, from 200 to 900, and more than 900). They are listed in Attachment II C. These two dimensions (category and size) yielded a 7 by 3 matrix, which is reproduced as Table I below. Firms have been tentatively allocated to individual cells to give an initial idea of a possible basis of more refined sampling. (Other criteria such as the stage of evolution of a firm, and the degree of specialization of its products were also considered, but not included in the matrix for the time being.)

Table I

Tentative Matrix of Hi-Tech Categories vs Firm Size for Use in Determining Sample

HIGH TECHNOLOGY CATEGORY	SIZE SMALL <200	MEDIUM 200-900	LARGE >900
1. AEROSPACE		3	3
2. APPLICATIONS	3	5	-
3. COMMUNICATIONS	3	3	3
4. ELECTRONIC COMPONENTS	6	3	-
5. HARDWARE (SYSTEMS)	5	3	5
6. SOFTWARE (SYSTEMS)	4	2	1
7. BIOTECHNOLOGY (ORGANIC)	-	-	-
	17	19	12

2. The Development of Further Lists from Businesses and Government Sources (Nov/Dec 1985)

This analysis, while useful and giving a framework on which to build, still left questions unanswered. What characteristics of firms in each of the seven very broad categories really identify them as firms at the leading edge of technological

development? Further advice was then sought, and obtained, from representatives of the Electrical and Electronic Manufacturing Association of Canada (EEMAC), the National Research Council of Canada (NRC) and the Economic Council of Canada (EEC), as well as Doug Barber, Vice President, Linear Technologies. In particular, some useful articles dealing with this question which has concerned (and continues to concern) the U.S. Government, the Organization for Economic and Cultural Development (OECD) of Western Europe and the Canadian Government, were obtained. Several of the most relevant are summarised below.

The U.S. Bureau of Labour Statistics (Tomaskovic,Dewey and Miller, Challenge, May-June 1983) approached the question by locating, naming and testing the following three definitions:

1. The "Sci-Tech" definition includes those industries with high levels (13.7 percent or more) of scientists, engineers, and technicians in their labor force.

2. The "R & D" definition concentrates on industries with an above-average intensity (9.6 percent of investment) of research and development.

3. The "Mass" definition (so-called because it originated in the Massachusetts Division of Employment Security, and does not have the quasi-formal status of the other two) combines two criteria: a high proportion of scientists and technicians, and a highly skilled labor force.

On the basis of the first definition, the authors identified 25 industries. However only the following eight satisfied all

three definitions: - drugs; office and computing machines; communications equipment; electronic components; engineering and scientific instruments; measuring and control instruments; optical instruments; and photographic equipment and supplies. To these eight, they added opthalmic goods, which had previously been part of one of the eight.

In a Canadian context, Bird (Policy Options, September 1984) claims that

> "what most people seem to mean by high tech industries are those research-intensive manufacturing industries, generally with a high proportion of professional and technical employees, which are actively innovating and expanding".

On this basis, he identified a group of five industries - pharmaceuticals, office equipment, communication equipment, electronics and scientific instruments, and extended this "narrow" definition to a broader and broadest definition, which can be compared with definitions from the U.S, since the narrow definition was chosen to match the U.S. B.L.S. definition already noted. Those industries added in the broader definition are: miscellaneous metal and other electric products (making 7), while other chemicals and aircraft are included in the broadest definition which has 9 categories. According to Bird's source (Statistics Canada March 1983), these high tech industries (narrow, broader, broadest) account for 8.6%, 11.7% and 18.3% respectively of Canada's total manufacturing employment. Bird's data allows one to obtain figures indicating the relative size

of each component hi-tech industry (Bird, Table 1, pg. 24).

In the Spring 1984 issue of Occupational Outlook Quarterly, Riche, Hacker and Burgan developed operational definitions of High Technology in the U.S. using specific criteria involving i) the utilization of scientific and technical workers, and ii) R&D expenditures. A third definition represents a combination of these. The table below summarises the criteria and the results.

Criterion	No. of Industries Obtained
1. Proportion of scientific and technical workers at least 1.5 times the average for all industries (PST)	48
2. Ratio of R/D expenditures to net sales at least twice the average for all industries (R/D:S)	6
3. Combination of 1 and 2 with PST at least average and R/D:S at least close to average	26

Excerpts from a private study of the Hi-Tech sector in Canada by W. Hutchison and Co., Toronto, were kindly released as a result of an interview with Mr. Hutchison. The survey covered 1500 companies in Canada. A percentage distribution was obtained for companies in 11 categories accepted as hi-tech. Data on the size of firms was also obtained, which showed that

72% of the firms sampled had less than 50 employees, with only 5% having over 1000 employees. Skilled and professional labour in the companies surveyed was high, of the order of 75% in the early 1980's. It is hoped that this data may be available for use in the proposed full-scale study.

Other sources in the Canadian government infra-structure such as the National Research Council (NRC) and the Economic Council of Canada (EEC) have also been actively examining this thorny question. Work done by Grimley resulted in a list of 5 major growth high technology industries, while McMullen of EEC has identified 11 Major New Technologies. Newton, also of EEC, examined a set of 33 industries already listed in a previous Canada Employment and Immigration Commission Study by Magun and Shingadia. From these, he identified a group of 5 highly related "high-tech" industry stars, which had very rapid growth rates.

The list of 12 areas originally developed for the study in 1984, the more recently developed list of 7 areas derived from them and other relevant data obtained in early Fall 1985 in Stage II have been re-listed for comparison with the lists derived by the U.S. Bureau of Labor Statistics, and the five Canadian sources just discussed - Hutchison, Bird, Grimley, McMullen and Newton. The eight lists are shown in Table II overleaf.

Table II

Comparison of Lists of Hi-Technology Industries Derived During 1984 and 1985

A. Lists Derived by Early Fall 1985

1. Compiled Spring 1984	2. Derived From List #1 and Other Sources (Fall 1985)
Office Automation	Aerospace
Computer Hardware	Applications
Computer Software	Communications
General Electronics	Electronic Components
Avionics & Military	Hardware Systems
Medical	Software Systems
Photonics/Microwaves	Biotechnology
Communications	
Biotechnology	
Consumer Products	
Robotics	
Materials	

B. Lists Derived from Government and Business Sources Nov/Dec 1985

Grimley NRC 1983	U.S. Bureau of Labour Stats. 1983	Bird Toronto 1984
Solid State Elect.	Drugs	Pharmaceuticals
Computer Sciences	Office Computers	Office Equipment
Specialty Polymers & Surfaces	Communications	Communications Eqpt.
Composite Materials	Electronic Components	Electronics
Earth Sciences	Eng./Sci. Instruments	Scientific Instruments
	Meas. & Control Instr.	Misc. Metal Products
	Optical Instruments	Other Electronic Prod
	Photographic Eqpt.	Other Chemicals
	Ophthalmic Goods	Aircraft

Hutchison Toronto 1984	McMullen EEC 1984	Newton EEC 1985
Microelectronics	Advanced Materials	Computer Services
Optoelectronics	Microelectronics	Office Mgt. & Business Consult.
Communications Eqpt.	Office of the Future	Misc. Services to Business Mgt.
Tele-equipment Mfg.	Advanced Mfg.	Eng. & Sci. Services
Aerospace	Communications	Offices of Architects
Biotechnology	Artificial Intell.	
Advanced Materials	Software	
Software Systems	Biotechnology	
Telecomm. Services	Health Care Products	
	Instruments/Sensors	
	Energy	

3. Hi-Tech in the Context of Innovation and Business Excellence

Birch and McCracken (1984) in a very comprehensive research report covering U.S. industry entitled "The Role Played by High Technology Firms in Job Creation" see the High Technology sector of the economy as a small part of a much larger "High Innovation" sector. However, they claim that it serves as a "key ingredient for innovation throughout the economy". Innovation is of two kinds - creation and replacement - and is not always technology-driven. They examined three possible performance based measures of high innovation - turbulence, efficiency and growth.

Turbulence misses many highly innovative industries. Efficiency as a measure is dominated by wholesaling and also misses much of the innovation in manufacturing areas, yet efficiency as a measure appears to be the key to U.S. innovation through the application of new efficient techniques - in many areas - building, travel, financial services and health care. Growth as an indicator, while indirect, captures well the results of innovation, yet needs to be studied over a long enough period to distinguish genuine growth from growth due to some special phenomenon in a shorter single period of time.

Birch and McCracken conclude that this is a time of great turbulence and of rebuilding which requires the quality of creativity above all - creativity which on the one hand reveals itself by its skill in putting technology to work, but on the other by being as innovative in dealing with the human consequences and needs which rebuilding brings - retraining, reeducation, and rehabilitation generally for those unable to be

retrained or reeducated.

This more general approach to viewing "hi-tech" firms in the wider perspective of innovation and creativity leads to the question of what constitutes excellence in a business or organisation, and hence what criteria might be used to identify "hi-tech" firms of high quality.

Determining excellence is clearly a major question, and recent years have seen it addressed internationally, especially as the Japanese became a worldwide force in business areas such as photography, audio-visual products, computers, and automobile technology. Recent books such as "The Pursuit of Excellence" by Gordon and its British equivalent "The Winning Streak" by Goldsmith and Clutterbuck have been devoted to this theme. The latter study for example focussed mainly on 23 companies which stood out from the crowd on the basis of:

1. High growth in assets, turnover and profits over the past 10 years,
2. A consistent reputation as a leader,
3. A solid public reputation.

Eight factors were identified by them as contributing significantly to success. They were - leadership, autonomy, control, involvement, market orientation, zero basing, innovation and integrity. The results seemed to apply to all sizes of business.

In the U.S., the annual survey of corporate reputations by Fortune magazine for 1985 (Toronto Globe and Mail, December

23,1985) required 8000 executives, directors and financial analysts to rate companies on the following eight attributes - quality of management; quality of products or services; innovativeness; long-term investment value; financial soundness; ability to attract, develop and keep talented people; community and environmental responsibility; and use of corporate assets.

A useful set of occupational Training Families and their key purposes, obtained in the U.K. by the investigator in 1985 is included as Attachment III for reference purposes.

CONCLUSION

For the purposes of the proposed research study, the present intention is to continue to collect relevant data on companies which can clearly be defined as either creating or using hi-technology of some accepted kind (microchip, laser, etc.). Such data will include items such as R&D expenditures and other financial indicators (see for example The Financial Post, Oct 12, 1985, the Toronto Globe and Mail Report on Business 1000, June 1985) and leadership and management data. This data will then be used in conjunction with other criteria such as growth rate and proportion of knowledge workers to produce a pool of possible firms to be sampled. The advice and recommendations of suitable individuals knowledgeable about the field of high technology and business will be sought to enable a final selection to be made.

Present intentions are to focus on a relatively small, yet operationally representative number of firms and organisations

defined by a wide definition of high-technology along the lines suggested by McCracken and Newton, and to study each in reasonable depth. A first approximation to areas from which choices would be made might be the following:

- Communications
- Software (Systems) including Artificial Inteligence
- Advanced Materials
- Advanced Manufacturing Technology (Robotics, CAD/CAM, CIM)
- Optoelectronics (Lasers, Video)
- Hardware (Systems)
- Applications (Health, Office, Travel, Banking, Education)
- Biotechnology.

As well as developing files in most of these areas, the investigator was able to establish first hand perspectives and valuable contacts by attendance at a one-day seminar in November 1985 in Ottawa on Office Automation run by the Canadian Information Processing Society, and on Banking and Government Uses of hi-technology such as Training in the Correctional Services Ministry by attending the Fourth Canadian Symposium on Instructional Technology, also in Ottawa, in early May, 1986.

ATTACHMENT I

A. Bibliography of Major Sources

B. Lists Derived from Four Major Sources

C. Lists of 22 High-Technology Industry Areas Derived from Four Major Sources, May 1984

A. Major Sources

1. The CATA-log (April, 1983) a directory to corporate membership - their identity, qualifications, products, and services. Ottawa: The Canadian Advanced Technology Association

2. Toney, Albert and Tilling, Thomas (1983). High Tech How to Find and Profit from Today's Super Stocks. NY: Simon and Schuster.

3. Unit on Emerging - Science and Technology (March, 1984) - area descriptions entitled 'Microelectronics and their Applications', 'Biotechnology and its Applications', and 'Materials'. Ottawa: The Science Council of Canada.

4. Federal Supply Classification Cataloging Handbook H2-1, Groups and Classes (Oct. '83). Ottawa: Department of Supply and Services, Canada.

5. supplemental sources:
   (i) Canada Tomorrow Conference Summary
   Minister of Supply and Services Canada 1984
   (ii) D. H. Crawford files:
   'Montreal Engineering Company'
   'Mitel'
   'Alan Wyatt'
   'Evert Communications'
   'Professional Associations'
   'Science Council of Canada'
   'Biotechnology'
   'High-Tech Applications'
   'High-Technology magazine "Resources" "Insights "Investements"'
   'Kanata High-Tech Training Association'
   'Gandalf- Patterson'
   'Statistics Canada'
   'Employment/Immigration Canada'
   'Company/Corporate Literature'
   'Companies and High-Tech Occupational Categories'

B: Lists Derived from Main Sources

I CATA-Log, The Canadian Advanced Technology Association

1. Avionics and Military
2. Communications
3. Medical and Testing
4. Computer Systems and Components
5. Scientific Equipment
6. Electronics
7. Office Automation, Computer Education & Training, Software
8. Other

II High-Tech How to Find and Profit from Today's Super Stocks, A. Toney T. Tilling

1. Genetic Engineering
2. Robotics
3. Cellular Mobile Radio
4. Fiber Optics, Lasers, and Microwaves
5. Applications Software Packages
6. Custom Circuits
7. Personal Computers
8. Computer Graphics
9. Data-Base Services
10. Video and Advertising Technology
11. Office Automation
12. Consumer Products
13. Medical Technology
14. Military Technology

III Unit on Emerging Science and Technology, Science Council of Canada

Microelectronics and their Applications

1. Microelectronics Devices
2. Optoelectronics
3. Computing and Computing Hardware
4. Software and Software Development (including A.I.)
5. Communications
6. Bioelectronics

Biotechnology and its Applications

1. Production Technology/Vectors
2. Products i) biosensors and bioelectronic devices
   ii) recombinant DNA
3. Process Applications

Materials

1. Plastics/Polymers
2. Superconductors
3. Metals
4. Ceramics
5. Glass
6. Paper (plant fiber)
7. Structural Fibers
8. Composites
9. Cement and Concrete
10. Refractory Materials
11. Fiber Reinforcement of Metals
12. Lightweight Materials
13. Substitutes for Harmful Materials
14. Renewable Materials
15. New Fabrication Techniques
16. Finishes and Surface Deposits
17. Thin Films and Adhesives
18. Bearing Materials

IV Federal Supply Classification Cataloging Handbook H2-1, Department of Supply and Services, Canada.

Weapons Nuclear Ordnance Ammunition and Explosives Guided Missiles	Military
Aircraft; Structural Components, Components, Launching, Landing, and Ground Handling Equipment	Aviation
Space Vehicles	Aerospace
Mechanical Power Transmission Equipment Communication Detection and Coherent Radiation Equipment Alarm and Signal Systems	Communications
Electrical and Electronic Equipment Components Electric Wire and Power and Distribution Equipment	Electronics
Fiber Optics Materials, Components, Assemblies, Etc.	Fiber Optics
Medical, Dental, and Veterinary Equipment and Supplies Instruments and Laboratory Equipment Training Aids and Devices Photographic Equipment	Medical and Scientific
General Purpose Automatic Data Processing Equipment Office Machines, Text Processing Systems and Visible Record Equipment Office Supplies and Devices	Office Automation
Nonmetallic Fabricated Materials Nonmetallic Crude Materials Metal Bars, Sheets, and Shapes Ores, Minerals, and their Primary Products	Materials
Musical Instruments, Phonographs, and Home-Type Radios Recreational and Athletic Equipment Photographic Equipment	Consumer Products

I C. List of 22 High Technology Industry Areas Derived from Four Major Sources (May 1984).

	CATA-Log breakdown	High-Tech fields (Toney & Tilley)	Science Council of Canada area descriptions	Federal Supply Classification categories
1. Computer Hardware@	*		*	
2. Personal Computers		*		
3. Office Automation@	*	*		*
4. Software and Software Development@	*	*	*	
5. Computer Graphics		*		
6. Database Services		*		
7. Video and Advertising Technology		*		
8. Consumer Products@		*		*
9. Electronics@	*			*
10. Bioelectronics			*	
11. Microelectronic Devices			*	
12. Custom Circuits		*		
13. Scientific Equipment@	*			*
14. Avionics and Military@	*	*		*
15. Aeroscpace				*
16. Medical & Testing@	*	*		*
17. Robotics		*		
18. Fiber Optics, Lasers and Microwaves@		*	*	*
19. Communications@	*		*	*
	(7)	(12)	(6)	(9)

Attachment I C (continued)

	CATA-Log breakdown	High-Tech fields (Toney & Tilley)	Science Council of Canada area descriptions	Federal Supply Classification categories
20. Genetic Engineering@	*	*	*	
21. Biotechnology: products, technology & applications		*		
22. Materials@			*	*
	(8)	(14)	(8)	(10)

@chosen as a final category

ATTACHMENT II

High Tech Firms and Categories
(Fall 1985)

A. List of Sources Used

B. Derived List of 96 Firms

C. Forty-Eight High-Tech Companies
(ordered by number of employees, Nov 1985)

D. List of Nine High-Tech Areas
(T. G. Mail Business 1000 Report for 1985)

A List of Sources Used

Stock Exchange Listings of
i) Walwyn Stodgell Cochran Murray Limited
ii) McLeod, Young, Weir Limited

Toronto Globe and Mail Business Report 1000 for 1985

Canadian Advanced Technology Association (1985) Membership List, Ottawa

Computer Systems Sources in Ontario Guide to Canadian Producers of Computers, Word Processors and Components, Software and Services (1985); Toronto: Ontario Ministry of Industry and Trade.

B List of Ninety-six Firms Derived from the Five Sources in Part A

1. CAE
2. Canadian Marconi
3. Fleet Aerospace
4. Haley Industries Ltd.
5. Leigh Instruments
6. Spar Aerospace
7. Circo Craft
8. Firam
9. Helix
10. Linear Tech.
11. Lumonics
12. Siltronics
13. Triple Crown Electronics
14. Varah, L. A.
15. Comterm
16. GEAC
17. Lanpar Tech.
18. Meridian Tech.
19. Orcatech
20. Xerox Canada
21. BMB Compuscience
22. Sydney Dev. Comp.
23. CTG Inc.
24. Develcon Elec.
25. Gandalf Tech.
26. Glenayre Elec.
27. Mitel Corp.
28. Northern Telecom
29. TIE Canada
30. Std. Modern Tech.
31. Cableshare
32. Canadian General Electric
33. Canadian Marconi
34. Computer Innovations
35. Federal Pioneer
36. G & B Automated Equipment
37. SHL Systemhouse
38. Fathom Oceanology
39. Sensormatic
40. Westinghouse Canada
41. Electrohome
42. Greyhound Cptr.
43. Central Dynamics
44. Datatech Systems
45. Comtech Group
46. Petro-Sun International
47. Zavitz Tech.
48. Omnibus Cptr.
49. Baxter Tech.
50. Scintrex
51. Epitek International
52. McPhar Inst.

53. Accugraph
54. ACDS Graphic Systems
55. Adminet Inc.
56. Advanced Elec. Sys.
57. AES Data Inc.
58. Alias Research
59. Atomic Energy Canada
60. AVEC Tech.
61. ens Bio Logicals
62. Boyd, Stott & MacDonald Tech.
63. Calian Tech.
64. Canada Systems Group
65. Canadian Applied Tech.
66. Canadian Astronautics
67. Canadian Cabinets
68. Canadian Ed. Microprocessor
69. Canpolar Consultants
70. Canstar Comm.
71. Canutel Industries
72. Cavalier Info. Sys.
73. Cognos Inc.
74. COM DEV
75. Cominco Elec. Materials
76. Compris
77. Computational Methods
78. Computer Assembly Systems
79. COS Electronics
80. CTF Systems
81. Cymbol Cybernetics
82. Datem Ltd.
83. Dees Comm. Eng.
84. Demand Research Consultants
85. Dictograph Intercom
86. Didak Mfg.
87. Dipix Systems
88. Documented Circuits
89. DY-4 Systems
90. Eidetic Systems
91. Exocam Systems
92. Footit-Mitchell
93. Foundation Instr.
94. Fulcrum Tech.
95. Gandalf Systems Group
96. Genesys Group

C Forty-Eight Hi-Tech Companies (Ordered by Number of Employees)

No. of Employees	Company Name	Number in Group
47,000	Northern Telecom	
13,032	Canadian General Electric	
	Xerox Canada	
5,500	Westinghouse Canada	
5,098	Mitel	12
4,000	CAE Industries	
3,000	Canadian Marconi	
2,500	Federal Pioneer	
2,200	Electrohome	
2,171	Spar Aerospace	
1,004	Gandalf	
900	GEAC	
700	TIE Canada	
700	Firan	
650	SHL Systemhouse	
650	Fleet Aerospace	
560	Leigh Instruments	
	Greyhound Computer	
525	Computer Innovations	
507	Circo Craft	19
460	CTG Inc.	
	Petro-Sun International	
404	Lumonics	
400	Comterm	
350	Haley	
313	Develcon	
260	Meridian Technologies	
236	Triple Crown Electronics	
217	Sydney Development	
200	Baxter Technologies	
200	Scintrex	
191	Glenayre	
189	Central Dynamics	
160	Epitek	
150	Varah	
150	Datatech	
150	Linear Technology	
130	Siltronics	
130	Fathom Oceanology	17
123	Cableshare	
110	Comtech	
100	BMB Compuscience	
73	G&B Automated Equipment	
56	Zavitz Tech.	
35	Sensormatic	
30	Orcatech	
26	Helix	
15	Omnibus	

D List of Nine High-Tech Areas

(from T.G.M. Business 1000 Report for 1985)

Computers

Aerospace

Electronics

Software

Data Communications

Electronic Components

Resource Technologies

Telecommunications

ATTACHMENT III

OCCUPATIONAL TRAINING FAMILIES (OTF'S) AND THEIR 'KEY PURPOSES'

OTF NO.	OCCUPATIONS	KEY PURPOSES
1	Administrative Clerical, and Office Services	Information processing
2	Agriculture, Horticulture, Forestry and Fisheries	Nurturing and gathering living resources
3	Craft and Design	Creating single or small numbers of objects using hand or power tools
4	Installation, Maintenance and repair	Applying known procedures for making equipment work
5	Technical and Scientific	Applying known principles to making things work or usable
6	Manufacturing and assembly	Transforming metallic and non-metallic materials through shaping, constructing and assembling into products
7	Processing	Intervening into the working of machines when necessary
8	Food preparation and service	Transform and handle edible matter
9	Personal service and sales	Satisfying the needs of individual customers
10	Community and health services	Meeting socially defined needs of the community
11	Transport services	Moving goods and people

* From F.E.U. occasional paper, Occupational Training Families - Their Implications for F.E. Ron Johnson, Nov. 1984.

APPENDIX V

COMPUTER SCIENCE, MATHEMATICS AND THE SCHOOL CURRICULUM

APPENDIX V

COMPUTER SCIENCE, MATHEMATICS, AND THE SCHOOL CURRICULUM

Emergence of Computer Science as a Crucial Modern Discipline

The single most significant force underlying most of the current wave of technological development is the digital computer. This will be the case for some time to come. From complex VLSI (Very Large Scale Integrated) circuit design to expert software systems bordering on machine intelligence, computer science is being called upon regularly to provide new solutions to a myriad of problems. Those persons who accept and embrace this technology, as either creators or users, may well be separated by social advantage over those who do not.

Computers, both digital and analog, were conceived, built and proven feasible by engineers as a means to an end - fast calculations. Mathematicians, recognizing the possibility for abstraction of the processes involved in computation, took a more theoretical viewpoint justifying the study of computation as an end in itself. The combined result of these two complementary perspectives became the academic discipline of computer science. Given the perceived usefulness of the results of computer science by society at large, this relatively young discipline has matured at an extraordinarily accelerating rate.

Computer Science, Mathematics, and Engineering

Scherlis and Shaw, of Carnegie Mellon University (Scherlis and Shaw, 1981), define computer science as "the study of algorithms, the representation and organization of information, the management of complexity and the relationship between computers and their users". Although computer science is like mathematics and engineering, it is different from both. Like mathematics, computer science requires a specific body of knowledge, it is communicated via a blended symbolic and natural language, and requires the intellectual skills of abstraction, analysis and synthesis. However, in comparison with mathematics, computer science is less concerned with formal proofs and the existence of structures, although these techniques are invaluable in program verification. Like engineering, computer science is a pragmatic, problem-solving endeavour concerned with the selection, evaluation and comparison of design alternatives for implementation. However, computer science deals more with abstract entities, like mathematical concepts, than with the concrete measurable quantities associated with engineering.

Mathematical Needs of Computer Science

Computer science concentrates on the behaviour of algorithms, data representations and computer organizations. As such, the computer professional requires more education than training in coding and debugging computer programs. He/she relies on support from mathematics with regards to relevant knowledge, intellectual skills and behavioural attitudes. Based

on the literature and discussions with several computer professionals, it is felt that the following needs of the computer scientist can be served by a suitable background in mathematics.

1) Body of Knowledge

It is generally accepted that the topics of continuous mathematics will continue to be needed. Additional emphasis will be required on discrete mathematics and logic. The following lists illustrate several specific topics that are considered useful, if not essential, to computer science (Ashenhurst (1980), Koffman (1984), Kovalina (1983), Ralston (1984)).

Discrete and Finite Mathematics

- number systems and arithmetic
- functions and sets
- graph theory
- combinatorics
- statistics and probability
- linear algebra (matrices)
- theory of computation
- recursive definitions
- mathematical programming (Simplex)
- numerical methods, precision and error analysis
- algorithms

Logic

- formal proofs
- predicate calculus
- first order logic

These lists could readily be extended.

2) Skills

The intellectual processes of abstraction, realization and generalization are deemed crucial for computer science (Scherlis and Shaw, p. 90). The tools for problem solving must be developed, in particular the ability to break a large problem into smaller pieces which can be solved or built and tested separately, then integrated into larger units (Lamb, D., 1986). This idea of modularization is necessary to develop flexible computer programs and systems which are adaptable to a broad range of applications and can be verified to isolate individual effects. Well developed capacities for reasoning and divergent thinking are important to maintain a clear view of the problems being solved and to consider the many options for solutions. Effective communication skills are increasingly being recognized as vital to the transfer of technological ideas. This necessitates a sophisticated verbal and written command of both natural and symbolic languages. Other forms of communication are expected to play a significant role with the growing use of visual, tactile and other man-machine interfaces. At the school level, exciting work continuing to be done at the University of

Toronto by Martin Lamb and others on gesture-based computer dialogue, which has already resulted in the creation of MENULAY II - an interactive user interface management system allowing "program designers to construct and refine both software and hardware interfaces" (Lamb, M., 1984 and 1986). The principles associated with graphic and artistic design are increasing in importance with the proliferation of computer graphics, Heckel emphasises in particular the need for software designers to think visually, and in terms of the user (Heckel, 1984). Analytical tools will need to stress the interpretation of such graphic information. Data and knowledge representation of abstract and worldly objects will require an ability to classify entities according to unique characteristics. Intuitive awareness of number size and estimation skills are important to deal comfortably with the measurable quantities associated with computers, where orders of magnitude in the pico- and giga-ranges are common.

3) Attitudes

Successful exploitation of the academic and theoretical potential of computer science is a social process replete with interpersonal activities. The ability to work effectively in teams, either as a leader or member, is important. With the ever-decreasing life cycle of computer-related products and systems, it is necessary for workers to remain flexible to adapt to a barrage of new, but often similar, situations. Like engineering, computer science demands methodical planning paying

strict attention to detail and accuracy. According to Birch and MacCracken (1984), the strength of the U.S. economy relies on the creative skills of putting technology to work rather than the production of technology per se. This implies a need for recognizing the computer as a sophisticated machine that is only as powerful as the uses to which it is applied by thinking, innovative individuals. Computer technology will have no impact on the future on its own.

Implications for the Proposed Study

Since the aim of the proposed study is to focus on how the mathematics curriculum will be affected by high technology, the continuing impact of computer science needs to be reflected in the emphases developed in the research instruments. Some attempt to do so has already occurred in the pilot study, as can be seen by examining each of the four instruments used.

In preparation for the major proposed study, it is anticipated that further discussions will be held with selected computer science specialists to try to identify specific emerging areas in the application of the discipline of computer science which are likely to impinge, directly or indirectly, on the use of mathematics in high tech industry and hence may have future implications for the math curriculum. For example, fuzzy logic which is increasingly used in declarative languages to develop expert systems is one specific area needing to be examined. The end result will then be input to the design of the instruments to be used in the actual study.

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APPENDIX VI

THE IMPLICATIONS OF HI-TECH INDUSTRY FOR THE SCHOOL MATHEMATICS CURRICULUM*

REPORT OF A
PILOT STUDY CONDUCTED AT
SUBSCRIBER SWITCHING DIVISION
NORTHERN TELECOM, BELLEVILLE
FALL 1985

BY

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FEBRUARY, 1986

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INTRODUCTION AND ACKNOWLEDGMENTS

As a result of an interview with Dr. Robin Jackson, Manager, University Liaison, Bell Northern Research, Ottawa in early 1984, contact was made with Bill Mullins, in Belleville, former human resources manager of SSD, Northern Telecom, Belleville, who recommended contacting the present manager of human resources, Ron Sweet, for permission to conduct a pilot study there.

The decision to consider the N.T. Belleville plant as the focus for the pilot study was based on the knowledge that N.T. is probably the leader in the hi-tech field in Canada. The area involved - communication - is also one at the centre of the hi-tech revolution, and the firm has a well established national and increasingly international reputation. In addition, the size of the SSD Division plant seemed to afford the opportunity to look in some detail at the many different organizational facets of hi-tech industrial operation.

A preliminary discussion was held with Ron Sweet late in May 1984 and an attempt made to meet with Dave Willmot, Director of Quality Control. However, due to the author's illness at that time, it did not prove possible for the investigation to proceed further until his return from sabbatical leave overseas in July 1985. Contact was again attempted but because the Belleville plant was closed in late July due to vacations, planning was delayed until early August 1985, when interviews were held with Ron Sweet, and Dave Willmot, and full cooperation obtained from them verbally for the conduct of a pilot study. Liaison was established on August 19 with Tom Freeburn, Compensation Manager,

who from there on, arranged visits and consultations over a period of some 3 months.

The author would like to acknowledge the very positive and sustained cooperation which he received from everyone he encountered at the Northern Telecom plant, in particular, the friendliness and help received from Ron Sweet, Tom Freeburn, and the staff of the Human Resources Division.

THE GENERAL PLAN AND CONDUCT OF THE PILOT STUDY

The Sample Used for Interviews

In order to choose a sample of employees which would be as representative as possible in terms of the purpose of the study, the author had several discussions with human resources and management personnel over the period from August 19 to September 12, 1985.

It appeared that the organization could be viewed "horizontally" in general terms as composed of the following eight areas: technology; manufacturing engineering; production; quality; marketing; business systems; comptroll; and human resources. As regards levels of responsibility and seniority, "vertical" structure, the situation was rather complex, as there were 6 levels of managers, 4 of engineering/specialist, 7 grades (22 through 28) of production worker and 10 grades of clerical worker. Table 1 summarises this vertical structure, while Table 2 gives the actual composition of the sample.

Table 1

Levels of Increasing Responsibility at SSD, N.T. Belleville

Details of Categories	Category of Employee			
	Manager	Engineer/ Specialist (APEO)*	Production Worker	Clerical Worker
Number of Levels/Grades	6	4	7	10
Description of each Level/Grade	Section; Department; Intermediate; Senior; Director; Division.	Entry; Junior; Intermediate; Senior.	22 Repetitive Assembly 23 Bench Assembly 24 Machine & Bench Assembly & Repair 25 Mechanical Assembly Coordinator; Intermediate Level Machine Operator 26 Lay-out Operator 27 Test/Repair Technician 28 Senior (system level) Technician	10 grades

* Association of Professional Engineers of Ontario

Table 2

Composition of Sample

Distribution of Employees		Level/Description of Employees Interviewed				
AREA	Number	Manager and above	Engineer/ Analyst	Technologist/ Specialist/ Programmer	Production or Clerical Worker	Total Number
Technology	169	2	2	2	-	6
Manufacturing	114	1	3	2	-	6
Production	749	3	-	-	6	9
Quality	30	2	2	2	-	6
Marketing	117	3	-	1	-	4
Business Systems	33	-	1	1	-	2
Comptrol	34	-	2			2
Human Resources	16	2	1	1	1	5
TOTAL NUMBER	1262	13	11	9	7	40

Emphasis was least in the production area in the sense that only 9 of 750 employees were interviewed. This was necessary simply because of the time involved for each interview (about 40 minutes), and of the need to sample from the other major areas within a period of two months at most. Of the 9, 6 were production workers of various grade levels (see page 7) and 3 section managers. Apart from production, emphasis was divided proportionately between technical (18 out of 313) and non-technical (marketing and control) (13 out of 200). Overall, the sample size was just over 3%, but over 6% discounting production. Most of the managers interviewed were section or department managers, but included were one Director (Dave Wilmott) and Rajan Goulet, (see later) as well as Ron Sweet (Human Resources Manager).

Sampling was reasonably equitable across levels of responsibility with 13 managers, 11 engineer/analysts, and 9 technologist/ specialist/programmers, with a similar distribution across Grades 22 to 28 for production workers.

The actual choices of individuals were made by Tom Freeburn, the Compensation Manager, on the basis of requests for as representative a selection as he could make subjectively, based on his extensive knowledge of the work force. Also the choices were made sequentially as each phase of the study developed. Table 3 gives an overall summary of the extent of the interviewing, giving the time sequence in which interviews were conducted together with the number of questionnaires completed and analysed.

Table 3

Summary of Interview Instruments and Distribution of Responses

AREA in Subscriber Switching Division	Phase and Interview Period	Number of Employees Completing Specific Interview Instruments				
		Basic (1)	Processes (2)	Elem-Sec Content (3)	Sec-Post Secondary (4)	Total No. of Instruments Completed
Production	1A	6	6	-	-	12
Manufacturing	Aug. 23 to Aug. 28	6	3	-	-	9
Engineering						
Production Manager	1B	*	*	3	-	3
Quality	Sept. 12	-	1	3	1	5
Technology	II	1	3	2	4	10
Marketing	Sept. 12	2	1	2	2	7
Business Systems	to	2	1	2	2	7
Comptroller	Oct. 11	1	1	1	1	4
Human Resources		2	2	2	-	6
TOTALS		20	18	15	10	63

* validated instruments completed by production workers

The First Phase (August 21-September 12, 1985)

1. Methodology and Instruments

A similar study on Mathematics in Employment (16-18) conducted by the School of Mathematics, University of Bath, England, in 1981 was used as a model from which to gain ideas about methodology and procedures (Bailey, 1981). The research team there was directed to consider "the mathematical requirements of the employment undertaken by those pupils who leave school between the ages of 16 and 18 in England and Wales". Their definition of mathematical requirements was as follows:

> "those processes or methods in use by the employees which could be viewed as mathematical."

A process was considered as mathematical if it required thought about a mathematical concept such as shape, size, number, and orientation.

Because in practice many people are unaware that they are in fact using mathematics, an approach which renders the mathematics which employees use (but are not aware of) more systematically visible is needed. For this and other reasons, the Bath research team decided to use only interviews and observations, and not to rely on the more indirect approach of the questionnaire. In writing up these personal and direct encounters, they tried to structure their written reports into the standard form reproduced below:

1. Contact (name, status)
2. Interviewee (name, qualifications on leaving school, Mathematics course followed at school)

3. Nature of Work
4. Training (in-company, Further Education? - which college)
5. Specific Tasks Incorporating Mathematics (S.T.I.M.) (description)
6. Mathematics Incorporated in Specific Tasks (M.I.S.T.) (abstraction of Mathematics from S.T.I.M.'s)
7. Comments

Particularly interesting were items 5 and 6, - the central part of the data collecting procedure - which focussed first on Specific Tasks Incorporating Mathematics (STIM) and then on Mathematics Incorporated in Specific Tasks (MIST). This approach had apparently been successful in the Pilot Study and so the author decided to use a similar one in designing the basic interview and observation procedure for the pilot study.

Discussions with Tom Freeburn on August 19 on the structure and organization of SSD, Belleville resulted in the decision to direct the first phase of the study to the production and manufacturing part of the overall operations of the firm and visits were arranged for August 21 and 23. The author prepared an interview/observation instrument along the lines of the procedures used in the Bath study. The version used (see Appendix I) was developed quickly, and had the following structure. Item I was introductory, explaining the purpose of the study, while items 2 and 3 requested details of the employee education and work reference. Items 4 and 5 comprised the STIM-

MIST sequence of the Bath study; they were followed by asking the interviewee to go to his/her work station, and demonstrate a typical task which they would perform. The interviewer was able to observe, ask further questions, and take appropriate notes. Questions on skills and tools used by the worker, and two questions about the worker's perceptions of school mathematics and how to improve it, completed the schedule. In using the instrument, the author first outlined the study and its purpose, then had the employee complete items 2 through 5, giving prompts and help as necessary. After the task demonstration, the procedure varied. Usually the employee completed the other parts, but occasionally if time was short, the author would retain the questionnaire, and simply obtain and record references to items 7 through 10.

Prior to the actual interviews with shop-floor employees, an opportunity was afforded on August 21 for the author to see workers being given skill training in assembling and testing components for the major production jobs, e.g., the SL1 printed circuit board. The author was able to secure a set of manuals and job descriptions outlining the nature of the various tasks and the skills needed to do them, and these were discussed with Tom Freeburn. Thus the worker grades involved ranged from Grade 22 (Repetitive Assembly) to Grade 28 (Senior Technician). (See also Table 2, p. 14) Discussions also took place with several of the shop managers who supervised the various assembly and testing departments involved.

Workers from three major production areas - manual assembly,

machine insertion, and repair testing, in different departments and at grade levels from 23 to 27 were selected with the help of three production managers, and made available for interview.

2. Interviews and Analyses

These first interviews took place on August 23 and August 26. Each interview consisted of two parts; a run through the schedule already described which took about 25-30 minutes, and the completion of the lower-order part of the process taxonomy developed in the spring and summer of 1984. Going through this part or the interview took some 10-15 minutes, so that each total interview lasted approximately 40 minutes. There were six such interviews. Full details of the development of this processes instrument are given in Appendix III.

The taxonomy (Instrument Number Two) was used as follows. Its make-up was first described briefly to each employee interviewed. They were then supplied with a copy of Part I on lower-order processes together with a "blanked-out" version showing only the left-hand column descriptions (see Appendix III). They were then asked to consider a typical task or job which they would perform at work, and compare the way they planned and carried out the job with the given set of activities/processes. Wherever they found a correspondence or matching, they were to list the details.

A second set of interviews with a selection of individuals from the Manufacturing Engineering Division organised by Chris Elliott took place on August 28, 1985. This time, the format was

different, as those involved were all technical employees - technologists, specialists or engineers. A general briefing of the six selected regarding the purpose of the study and the two interview schedules was held first, and then each individual was interviewed in sequence. Again, these interviews took approximately 30 minutes. In one or two cases, the individual preferred to complete the actual instruments himself. This had the supposed advantage of giving more time for reflection, but it also led in two cases to delay in obtaining the completed information.

Preliminary analysis was done on the completed production worker interviews - both the 'basic' and the 'process' schedules - and summary tables compiled from each analysis. It was felt that the results obtained should be checked with the department managers, and so a feedback meeting to do this was held on September 12. Their knowledge of the jobs and individuals involved supplemented the summary and confirmed the validity of the analysis (see Table 3 p. 6 and later section on Data Analysis). The analysis also showed that the questions on areas of content related to the shop-floor shop needed to be posed in a more systematic and detailed framework. The author therefore developed a third instrument - which is described below.

The third instrument used was a questionnaire consisting of basic content likely to be learnt by children from 5 to 16 years of age. It was primarily based on a summary of core content found in the Cockcroft Committee Report on School

Mathematics in the U.K. (1982). Chapter 6 (pp. 83-88) dealing with Mathematics in the Primary years and Chapter 9 on Mathematics in Secondary School (pp. 135-140) were particularly relevant. In Chapter 6, stress was placed on the need for practical work, and general activities, including model making (see Cockcroft p. 142), as well as on basic areas such as number and computation, shape and space, measurement (see Cockcroft p. 80), graphical work and logic. Chapter 9 focussed on a foundation list of 10 mathematical topics, basically an elaboration of those already noted, together with money, time, percentages, ratio and proportion and statistical ideas. In addition, the report stressed that the calculator and computer should be seen increasingly as basic tools in the study of mathematics for all.

A number of other sources were also consulted. These included the Ontario Association of Coordinators of Mathematics document on the school mathematics curriculum (K-13) (1979), Dienes (1978), Skemp (1971), and Stretch (1976). Stretch suggests an interesting common core of mathematics up to GCE O-level (age 16) consisting of these six areas - numerical relationships, spatial relationships, structure, social relationships, mechanical relationships, and manipulative skills. Each of these has a number of topic areas associated with it.

As a result, a content/topic summary was compiled, and used to develop a draft questionnaire (Instrument Number Three), which had 13 concept/topic areas, each with a list of associated sub-topics. This was completed in early September 1985, ready for

immediate use, although still in written form. Respondents were asked to check each topic - 62 in all - as essential, important, or unimportant firstly for a typical N.T. worker, and secondly for themselves in the specific job position which they held. The questionnaire was first used on September 12, with the three production department managers. It was typed up some weeks later and a copy of the summary and derived questionnaire are given in Appendix IV.

The Second Phase (September 12 - October 11, 1985)

By this point, it had been agreed that the investigator would complete the study by interviewing a small and reasonably representative sample from each of the following areas in the plant - quality, technology, marketing, business systems, comptroller, and human resources. In nearly all cases, these were to be people at the technical or managerial level to cover the secondary and post-secondary level. Because of this fact, the investigator felt he should develop a companion questionnaire/interview schedule to that for ages 5-16. This was done fairly hurriedly during the period September 12-19, and used first with Sam Ellis, Manager of Computer Integrated Manufacturing - a new department created about 2 years previously. Again, it was used in very rough draft written form, as much as possible as an interview instrument. A copy of this instrument (Number Four) is given in Attachment IV. It had two sections as follows:

I. Personal and Professional Data

II. Technical

with the technical section subdivided into three parts. The first part was prefaced by asking to what extent the respondent used secondary or post-secondary mathematics, secondary being defined as pre-calculus and pre-inferential statistics. Part I consisted of a list of topics at secondary level comprising 8 wide areas, e.g., traditional algebra and simple probability, followed by a post-secondary list of 13 topics, while Part II was a list of 8 well-known mathematical methods or techniques thought likely to be used by the employee. Finally, a number of more general possible areas of emphasis in advanced pure and applied mathematics, comprised Part III.

For the preface and Parts I, II and III respondents were asked to check one of 'frequently', 'occasionally', 'seldom' or 'never' as an indication of their usage of the levels, concepts, techniques and broad areas listed.

Interviews continued with employees from the various company areas mentioned once a week from September 12 through October 11, 1985. Altogether 20 more interviews took place. The total number of employees interviewed was 40 (Table 2, p. 6) and 63 schedules in all were completed, returned and analysed. This represented an overall return rate of about 80%.

The Final Phase (October 12 - November 19, 1985)

The next four weeks were devoted to analysis of the completed schedules and questionnaires. The study concluded with a final session on November 19, 1985 arranged to obtain feedback

on the study from people at N.T. Before this final session, the investigator constructed two further questionnaires - one on possible objectives of school mathematics, the other on possible qualities and skills desired in employees by employers. Tom Freeburn, Ron Sweet, and Rajan Gaudet, Director of Software Development were interviewed, and very useful verbal and written comments on the study and the two final questionnaires were obtained from them.

DATA ANALYSIS

The Basic Schedule (Instrument Number One)

Twenty questionnaires were completed - 13 by production, manufacturing, or technology employees, and 7 by employees from the other four areas. Generally speaking, all workers used the six areas identified in the questionnaire - calculating, measuring, basic geometry, algebra, statistics and graphs. Table I in Attachment I, summarizes uses by production workers. A wide variety of skills, varying from simple manipulative and visual through analytical skills were in use; similar variety was found in the aids and tools used, from the soldering iron and the use of coding with electrical components to quite sophisticated uses of the computer and associated software. Table II in Appendix I, shows data summarized from the 14 employees from areas other than production. The major comments and suggestions for improving school mathematics focussed on emphasis on applications, especially to business and home economics; the need

to use real-life problems and logical and creative thinking; and the inclusion of more computer-related education and experience of new technological methods and machines. The following two excerpts from two respondents, the first a design engineer, the second a market management specialist, give the general flavour.

> "More $ calculations required at high school level such as mortgages, annuities, amortization, return on investment etc.,."

> "School math requires more application-teaching. Everyone can relate more easily to model analysis and role-playing than theory presentation. We need to dwell more on the realistic role which math plays in everyday life, and take the emphasis away from theory/theorems."

2. The Activities/Processes Schedule (Instrument Number Two)

As indicated earlier, the processes questionnaire consisted of two parts - one on basic activities and processes and a second relating to higher-order composite processes, of which five were identified and described, ie., proving, problem-solving, mathematical modelling, mathematizing and investigating situations. A full description of the taxonomy itself, together with other uses for it as well as in this research study, is provided in Appendix III of the main report of the feasibility study.

18 people completed the lower-order process part of the

questionnaire - 13 from the design-production areas, and 5 from the marketing-control areas. It was clear from the interviews with the six production workers that they engaged in all of the six types of activity or process involved. Table I in Appendix III summarizes the data obtained. As noted earlier, copies of the completed table were discussed with the three section managers, who confirmed the validity of the results, and amplified some of the comments. At this level, greater emphasis was found in the areas of comparing, sorting, transforming by calculating, and reporting, but symbolising, analysing and conjectural and logical thinking were clearly being used frequently by the "higher" grade workers.

Similar frequent use of all of the six basic processes was found to take place in the work of the manufacturing engineering and other respondents. The results have been summarized in Table II, III, IV and V of Attachment II. In all cases at the specialist, engineer, design or managerial level, respondents acknowledged that they saw a clear correspondence between the activities and processes they used, and those identified in the taxonomy.

The formal use of the process taxonomy was concentrated on Part I - the basic processes, because of time pressures. However, a number of respondents indicated in their replies that they were really engaged in problem-solving, mathematical modelling, or proving. The following excerpts from one respondent, a design engineer, illustrates the reality that actually prevails.

"Difficult to break down the processes used in a working situation into its taxonomical parts. In general I study a given problem to see if it is similar in any way to something I've done before. I then collect information which I use to create hypotheses. After creating a hypothesis I set out to prove/disprove and along the way I often! find out more facets that lead to more theories and hypotheses. This process involves all of exploring, transforming, justifying, explaining, etc. It's also a recursive process."

The fact that basic processes are used as required in dealing with applied problems was also confirmed in responses to the final part of the "advanced" questionnaire developed for use in phase III of the study.

3. The Elementary/Secondary Content Schedule (Instrument Number Three)

Analysis of this was based on 15 responses, 8 from the "design-production" area, and 7 from the "marketing-control" area. Responses to individual topics were weighted as follows: essential - 4; important - 2; and desirable - 0. On this numerically based analysis, 14 (sub) topics gained a score of 30 or more (the possible maximum being 60). This minimum score was chosen since it could be gained by all 15 respondents rating a given item as important. Any higher score indicated that some respondent related the item as essential. Table I in Appendix IV summarizes the results for those topics.

Using a weighted numerical scale is always open to question, and conclusions based on such a system must be treated with caution. Of the responses made to these topics, important or critical was the judgment of at least 11 out of 15 for all topics except the two on geometry and the one on the use of the computer for tests and decision making. The exercise does show a high level of agreement on the usefulness of counting, the understanding and use of percent, and the use of the computer as a source of data. Twelve other topics, generally of an applied nature, e.g., collecting and tabulating data, estimating and accuracy, dealing with time intervals and problems, and using the calculator more intelligently (ordering operations, approximately) gained scores of 26 or 28.

4. The Secondary/Post-Secondary Schedule (Instrument Number Four)

As indicated already, this questionnaire was constructed rather hurriedly at short notice, part way through the pilot study. Ten people completed it - 5 from "design-production" (D-P)and 5 from "marketing-control"(M-C). Its function was seen as giving initial insights into the level of mathematics and the main techniques and methods employed and the context and problems associated with their use. The responses for each group of five were analyzed separately.

The main results were the following:

Level Used Secondary Mathematics was used frequently by eight of the ten (4 D-P, 4 M-C), while post-secondary mathematics showed frequent use by 3, and occasional use by 4 of the ten.

Most Used Topics At the secondary level, traditional algebra, and descriptive statistics were used frequently or occasionally by just over half of the ten.

At the post-secondary level, calculus, probability and statistics, and valuing (the application of mathematics to estimating, costing, etc.) were used by about half of the ten, but rather less frequently.

Methods and Techniques Algorithms and simulations designed for and used with computers were used frequently by six of the ten with mathematical modelling used by seven, but only occasionally. Data bases were used frequently by all ten, while spread sheets, graphics and testing and decision-making were used either frequently or occasionally by 5 to 7 of the ten.

Other Topics/Areas Of the various topics or areas of a general nature (see section V of the questionnaire in Appendix V), the frequency of use was relatively low, the most used being the Applied Mathematics related to Electricity and Electronics (used frequently or occasionally by 5 out of 10). The topics tended to be scientific or technological in nature and the positive responses reflected this, being almost entirely from the design-production sub-group.

Examples of Mathematical Problems Encountered A wide range of problems involving mathematics was reported. They included using the computer to simulate machines working so as to optimize production, the use of Venn diagrams to assist in the design and working of computer programs, application of rates and estimation in debugging and resource level requirements, and developing any

formulae or equations which were necessary for reporting information.

Generally speaking, the uses in the design-production area required the application of university as well as secondary mathematics, while those needed in marketing-control tended to be more basic, and non-sophisticated. Both seemed to require the ability to adapt basic or advanced mathematics to a variety of situations cropping up as computer technology raised new problems to be solved in a practical yet optimal way.

THE DEVELOPMENT OF TWO ADDITIONAL QUESTIONNAIRES

Need for Further Instruments

Although the instruments developed and used so far in the pilot study seemed appropriate and valuable, the author still felt uneasy about a lack of in-depth probing of the long-term relationship between mathematics (particularly at the school level) and the mathematical needs of industry. Some of this unease was related to the question of what proportion of time students spent actively learning, and what attitudes, and values the activities engaged in were producing. Recent research in education generally has been focussing on time on task (see for example Rosenshine, 1978) and in mathematics and science education where attention is being focussed by some researchers on meta-cognition areas (Baird and White, 1984; Kilpatrick, 1984). Questions such as what kinds of awarenesses and attitudes are developed by students when they are listening or copying notes versus working on routine exercises or group projects lead

to the whole field of what are/should be desirable affective as well as cognitive objectives in mathematics education. The author had previously (in early September) drafted a possible interview instrument designed to explore this area, but pressure of the on-going pilot study necessitated a postponement of its further development.

By mid-October, however, when the interview phase ended, the author reflected again on this attitudinal area, and began to see it as an overlap between some of the objectives of mathematics education and desirable skills, work-habits and qualities such as cooperativeness and flexibility which employers would want to find in employees. He had already addressed the objectives question in his 1976 work on the Ontario Secondary/Post-Secondary Interface Study, and had encountered thinking on the question of desirable qualities of employees while on Sabbatical Leave in the U.K.. He therefore decided to develop two further questionnaires, one on math objectives, the other on desirable employee qualities, and attempt to get feedback on them, at least from Northern Telecom, when they were completed.

Objectives in School Mathematics

The starting point for the objectives questionnaire was the work done by the author on general aims in mathematics during the 1976 Interface Study. At that time, using as basis a brainstorming session with a group of Ontario Mathematics educators and mathematicians, the author had compiled a set of 33 aims and objectives, some very general others much more specific.

These had been grouped in five classes - basic applied skills (1-5), personal work habits (6-8), basic mathematical abilities (9-15), higher mathematical abilities (16-23), and appreciation of mathematics (24-33). The original list of 33 aims was very comprehensive, and as can be seen from the names of the classes, ranged from the cognitive to the skills and attitudinal aspects of mathematics learning.

A number of respected sources which focussed on aims, objectives and justifications for learning mathematics were then consulted, their aims extracted and placed for comparison in paraphrased form in Table 4 - overleaf. The list of 33 objectives from the Ontario Interface Study was also studied, and a total of 11 of these (numbers 2, 7, 11, 18, 24, 26, 27, 28, 31 and 32) identified as similar to ones found in one or more of the major sources consulted.

These two tables were then used as a basis for constructing a taxonomy of objectives for school mathematics. The current form of this consists of 20 objectives, grouped in the following five categories: basic mathematical abilities (1-6), basic skills (7-10), appreciation of mathematics (11-15), attitudes to mathematics (16, 17), and higher mathematical abilities (18-20). Finally, the taxonomy was re-written in the form of a questionnaire which requested each respondent to check each given objective as critical, important, desirable or insignificant. The

TABLE 4

Aims and Justifications for Learning Mathematics

Crawford and Others 1976	Tayler, Tammadge Prescott 1971	Gardner, Glenn, Renton 1973	Coleman and Edwards 1976
Total of 33 objectives obtained by brain-storming grouped into 5 categories below: 1. Basic Math Abilities 2. Basic Applied Skills 3. Higher Math Abilities 4. Appreciation of Mathematics 5. Personal Work Habits	1. a language-vehicle for thought 2. enables precise descriptions and modelling 3. best vehicle for comprehending pattern 4. intellectual and aesthetic appeal and fascination of deep structural problems	1. for living and responsibile adulthood (functioning adequately as a member of society) 2. for livelihood/vocation 3. mode of knowledge and experience involving concepts of a general abstract kind (education) 4. significant part of aesthetic, affective aspects of human endeavour	1. understand what mathematics is and what it is not 2. mathematics is a way of thinking 3. mathematics is a cultural resource 4. mathematics is an essential language for communicating ideas

Diennes 1978	Agenda for Action 1980	Cockcroft 1982	Maths 5-16 1985
1. learn to abstract - strip off irrelevances 2. learn to generalize 3. learn to formulate and cope with precision and precise messages 4. learn to work together 5. learn to respect opinions/values of others	1. problem-solving as major focus of curriculum 2. basic skills to be extended e.g. include estimating and approximating; Use in predicting; computer literacy 3. emphasize applications, and appropriate skills and strategies e.g. formulating key questions; discovering patterns and similarities 4. integrate use of calculator and computer into curriculum 5. create classroom environments for problem-solving 6. emphasize communication skills and clarity	1. maths is useful since it provides a powerful, concise, unambiguous means of communication. 2. enables development of mathematical skills and understanding required for adult life, for employment and for further study and training - 3. and for study of other subjects 4. helps develop appreciation and enjoyment of mathematics itself.	set of 10 aims further divided into five categories of objectives. 1. essential element of communication 2. powerful tool 3. study of relationships 4. fascination of intrinsic appeal 5. a creative process/activity allowing use of imagination and flexibility. 6,7,8. enables systematic independent cooperative ways of working. 9. encourages in-depth study 10. gain confidence in doing math.

taxonomy and the derived questionnaire are given in Attachment V.

Desirable Employee Skills and Qualities

During his sabbatical leave in the U.K. from January to June 1985, the author focussed his studies on the general area of mathematical, science and technological education. Three events (and associated individuals) in particular contributed experiences and data relevant to the question of what skills and qualities employers would like to see in their employees. They were a one-day conference run by the Microelectronics Program in Nottingham in early February, 1985, (Ann Irving) the Annual Conference of the Mathematical Association in Dundee in April 1985 (Peter Coaker), and the second of two visits to the firm Thorn EMI in Hayes, Middlesex in late June 1985 (Bob Davies).

At the Nottingham seminar, Ann Irving, of Loughborough University listed the following 11 qualities and skills as wanted by industry from school graduates - an all-embracing list! To the basic skills of numeracy, literacy and ability to use logic, she added the following mental skills - thinking, analysis, planning and communicating. Also desired were judgement, activeness, creativity and adaptability. According to her, vocational skills could then be developed from a basis of these qualities and skills.

Peter Coaker, President of The Mathematical Association, an industrial mathematician and co-investigator in the University of Bath Study already cited, claimed the following as qualities and skills wanted by employers - literacy, numeracy, ability to

communicate in many media, trainability/flexibility, economic literacy, willingness to face responsibility and willingness to work with others. Bob Davies, Assistant Director, Thorn EMI, adds to these the need to be disciplined, and persistent and to be able to start, follow through and complete the solution of problems which the individual has identified as worthy of an investment of resources (Davies, 1977).

The work of Arthur De W. Smith in Canada on Generic Skills (1974), Tom Stonier of Sheffield University (Stonier, 1984) and the 1982 Report on The Information Society by the Education Commission of the States were also used in compiling an overall view of the employee needs of today's information-oriented industry. Stonier (1984) argues for the development of "professional generalists" who are capable of organizing knowledge vertically but also know how to use information technology, especially being able to obtain, record, manipulate, interpret and use relevant information. Basic skills needed are communication, systems thinking, flexibility and problem-solving.

Using these sources, fifteen desirable skills and qualities were identified and grouped in four categories - basic, analytic/synthetic, evaluative/creative, and (inter) personal. The resulting taxonomy was converted into a questionnaire on a similar basis to the one for objectives, and a copy is given in Attachment V.

INITIAL FEEDBACK ON THE STUDY

Feedback on the Two Additional Questionnaires

Although the questionnaires were developed too late to be included in the pilot study, limited feedback as to their potential usefulness was obtained in discussions with Ron Sweet on November 19. In his view, the first two sections of the objectives questionnaire - basic mathematical abilities, and basic skills were acceptable and worthwhile. He found sections III and IV (appreciation and attitudes) less appropriate for industry, as the focus in industry is on how and when mathematics should be applied. He felt that section V on higher abilities might be appropriate. He also suggested that the language used needed to be simplified.

Feedback from Other Managerial Staff

As indicated earlier, the author paid a special visit to Belleville after he had concluded the interviewing and data analysis. The purpose was to obtain feedback while the impact of the visits was still fresh in the minds of people who had cooperated in organising supervising, and advising on the personnel to be interviewed. A summary of the major items of interest and value for similar work in the future is given below.

According to Tom Freeburn, the author had used too much data in the interview instruments, and he emphasized the need to structure them, so that respondents could complete what was required in about half an hour. Regarding the simplified horizontal organisation of firms smaller than Northern Telecom,

he suggested a three-fold horizontal structure - Design and Production, Marketing and Sales, Management and Control. He saw 4 or 5 levels of vertical structure - hourly paid worker; specialist; engineer; manager; and executive. In a smaller firm, these might be reduced to three possibly by telescoping to specialist/engineer, and manager/executive. The question of to what level in the structure the interviewing should be directed yielded no clear answer. According to him, Northern Telecom was decentralized as to hiring with heavy reliance on line managers. A possible implication then is that it is at that level that a study of this kind should be directed.

Finally, a very worthwhile discussion was held with Rajan Goulet, Director of International Software Development. His main criticism of the "processes model" was that it was too linear, and lacked an essential feedback element. This comment was similar to the earlier quotation (pages 19, 20) outlining how a design engineer used these processes in carrying out a typical assignment, when he indicated that it was a highly recursive process. Both seem to be saying that they are in fact integrating these processes into one or more of the composite processes identified in Part II of the processes taxonomy.

Instead of attempting to answer the questionnaire, Rajan went to the trouble of putting on paper in simplified form the various phases involved in doing a "Software Development". Very briefly summarized, these were as follows:

Phase	Name	Brief Description
1	Estimating	Done before start to estimate cost and subsequent delivery date.
2	Scheduling and Planning	Cost estimates are used together with correction factors for complexity and human interaction to determine and refine delivery date.
3	Implementing	A detailed plan of all the steps needed to create, and perform the development as prepared, including the same final delivery date as in phase 2.
4	Delivering	This is the final and most important phase, comprising final testing and release of software to the customer.

It is interesting to compare this set of sequential phases, with the more mathematical/scientific ones of the processes taxonomy (both lower-order and composite). Clearly identified is the focus on costs of development at the start and final delivery of the product at the end, thereby setting the actual processes firmly in an applied commercial/industrial context.

RESULTS OF THE STUDY

The study just described was planned and carried out in the period from August through November 1985. However, the mathematical processes taxonomy was developed over a period of several months in the first half of 1984.

Forty employees distributed widely as to functional area and level of responsibility were interviewed. Each was asked to respond to one or more instruments depending on their specific job. Four interview instruments were used - a basic general one

for production and manufacturing engineering employees (20 responses); a mathematical processes one for all but a few senior employees interviewed (18 responses), an elementary - secondary one focussed on content for all except those interviewed in phase 1A (15 responses), and a more sophisticated questionnaire aimed at the managerial level in phase 2 (10 responses). (Details were given in Table 3 on Page 6.)

Results from the basic questionnaire confirmed that production workers were using basic mathematics in their daily tasks, sometimes being unaware that they were doing so. More widespread use of school mathematics was evident in the responses of other workers, especially at more responsible levels (see Tables in Appendix VI). Comments regarding their views of what school mathematics is today indicated a strong consistent view that it needs to be more applications-oriented, with a number of suggestions aimed specifically at increasing the focus on the more budgetery and commercial mathematics needed by the citizen in daily living.

The most interesting results, in the investigator's view, came from the responses to the mathematical processes instrument. Strong evidence was found that all employees were using, intuitively at lower responsibility levels, consciously at higher responsibility levels, planning and thinking activities and processes matching these identified in the taxonomy.

The development and use of the "5-16" content questionnaire also proved worthwhile. The set of topics was comprehensive, and the results indicated clearly the importance attached to the

ability to use the computer in various ways, most significantly to access and retrieve data. The other results were relatively unsurprising, and seemed to reflect particular job emphases. Since the results are based on only 15 responses, caution needs to be used in making generalizations.

Finally, the more advanced questionnaire designed to probe the use of mathematics at senior and post-secondary level revealed that University level mathematics was not used as frequently as might be expected. The use of the computer as a tool for dealing with design, technological, production and quality problems and tasks was clearly demonstrated, especially for developing algorithms and using mathematics; widespread use of it as a data-base, and as a financial analytic tool via spread-sheets was also evident.

DISCUSSION AND CONCLUSIONS

How successful was the study, and what are the implications for a possible more wide-spread study of the use of mathematics in so-called hi-tech industry?

To undertake such a study, the purpose must be very clear, and the planning and implementation refined to ensure the maximum return of valuable information with as little disruption of on-going work as possible. This dilemma can only be solved by careful public relations and planning beforehand, together with clear, concise instruments and interviews. In the pilot study, the pressure of time and need to learn the structure of the firm while conducting the actual sequences of interviews meant that a

measure of redundancy and lack of focus took place. At the same time, much was learned, and a good cross-section of employees across both functional areas and levels of responsibility was obtained.

As regards planning, it seems essential that a brief outline of the purpose, and methodology of the study be prepared ahead of time, contact made with a suitable liaison person, and the details of visits and personnel worked out in advance. The instruments to be used must also be prepared ahead of time, with the focus on the essential information clearly defined, including the time needed for interview/instrument completion.

In the proposed study, there are still a number of variables which need decisions made about them, such as the number and extent of the enterprises to be sampled, their size distribution, and the appropriate sample distribution within a given enterprise. These clearly influence the number, detail, and focus of the instruments to be used, as well as being themselves determined by the time and financial resources available for the study.

As indicated earlier, it is now the investigator's considered judgment that the proposed study should focus on three aspects of the mathematics curriculum - the content, the physical and mental activities and processes used by the student, and the attitudinal, personality, sociological, environmental context and tasks through which the learning is mediated. All of these interact with each other. The third aspect - the indirect learning of attitudes, abilities and skills is often left out of

account unconsciously or tends to be ignored in favour of the more clearly visible cognitive dimensions of content and thinking processes. The two questionnaires developed at the end of the study address this wider "ultra-cognitive" dimension. More thinking needs to be done by the investigator (1) to streamline the actual instruments used, and reduce them to a manageable time-line and (2) to find a way of adapting the final 2 instruments and including them in some way.

It may be that the final survey instrument has to be divided. Once again, the conflict between breadth and depth coverage comes into view. A possible division would be to have operational staff complete process and content questionnaires, managerial and executive staff complete a separate instrument directed to the 'quality' dimension, and a few key managers complete an instrument which examines all aspects.

If information on all these aspects of curriculum outlined above is required, it seems to the investigator that a case-study approach as opposed to a wide-varying survey would be more appropriate. If so, very careful choices of the firms, and organizations to be sampled will be a prime necessity.

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ATTACHMENT I

INSTRUMENT NUMBER ONE

BASIC

INTERVIEW AND OBSERVATION SCHEDULE

A SCHEDULE

B SUMMARIES OF RESPONSES FROM MAJOR ORGANIZATIONAL AREAS

(INSTRUMENT NUMBER ONE)

INTERVIEW AND OBSERVATION PROCEDURE
FOR USE IN PILOT STUDY
AT N.T., BELLEVILLE
FALL 1985

FIRST
DRAFT
AUG. 1985.

1. INTRODUCTION PURPOSE AND METHOD OF STUDY.
makes school math more relevant by

i) asking questions at different levels across hi tech industry.
ii) observing actual work being done.

2. DETAILS OF QUALIFICATIONS AND EXPERIENCE

i) Name

ii) School Leaving Qualifications

iii) Maths taken at school

iv) Training/Education since school

v) Working Experience

3. OUTLINE OF PRESENT JOB

i) Grade and Title

ii) Brief Description

4. WHICH TASKS DO YOU PERFORM WHICH INVOLVE MATHEMATICS? (S.T.I.M.) Describe them briefly.

5. WHAT MATHEMATICS DO YOU ACTUALLY USE IN THESE TASKS? WHEN?
   e.g. calculations, measuring, geometry, algebra, statistics, graphs.

6. OBSERVE INTERVIEWEE PERFORMING TYPICAL TASK.

7. WHICH PHYSICAL, OR COORDINATING SKILLS DO YOU USE?
e.g. manual sequencing, visual scanning.

8. WHICH TOOLS OR AIDS DO YOU USE?
e.g. soldering iron, scale/assembly drawings.

9. HAS THE MATHS YOU DID AT SCHOOL HELPED YOU IN THIS JOB?
If yes, how? If no, why not, do you think?

10. PLEASE MAKE ANY SUGGESTIONS YOU CAN FOR IMPROVING/CHANGING SCHOOL MATH TO MAKE IT MORE VALUABLE AND RELEVANT FOR YOUR JOB.
e.g. change emphasis on topics,
change teaching/leaving methods
identify difficult ideas, parts of the curriculum.

11. THANKS VERY MUCH.

D.H. CRAWFORD
AUG. '85.

USE OF MATHEMATICAL CONTENT
IN TYPICAL TASK BY PRODUCTION WORKERS

MATHEMATICAL TOPIC	Job Title and Area of Production Manual Operator Grade 23 Manual Assembly	Production Tester Grade 24 Repair & Testing	Machine Set Up Op. Grade 26 Machine Insertion	Machine Operator Grade 26 Machine Insertion	El Eng Tech. (Tester) Grade 27 Repair & Testing	EL Eng Tech. (Trouble Shooter) Grade 27 Repair & Testing
CALCULATIONS			Involved in all jobs listed below	Ordering components, time allowed for jobs.	Know and use square roots, calculate using formulae, estimating.	Check components for specified tolerances.
MEASURING	Lengths of wires. Exactness via marking path on board.		Read various instruments - lead diameters, depth gauges.	Know different sizes of components, know power wastages	Use test instruments for current, voltage, resistance.	Measure to test, possibly eliminate faulty component.
GEOMETRY	Use drawings. Locate components correctly.	Distinguish between components (R. C. Transistor)	Know shape, location of components.	Know different shapes, sizes, locate parts, know thickness, read drawings.	Know and use wave shapes, phase angles, trig. functions.	Use wave forms etc. on oscilloscope.
ALGEBRA	Know meanings of symbols and codes.		Use symbols for codes.	Use symbols in coding.	Use of symbols and formulae $X_c = \frac{1}{2\pi f_c}$	Use simple formulae $V = IR \quad P = I^2R$
STATISTICS			Record shortages in stock list, know changes in parts(discontinued), new programs.	Log daily runs	Use tally sheets to monitor failure in processes.	Use tally sheets to keep totals of various faults.
GRAPHS	Use assembly drawings.			Read data and adjust on VCD and other machines.		Use of wave forms.

SUMMARY OF RESPONSES TO BASIC SCHEDULE BY

MANUFACTURING ENGINEERING

JOB TITLE	TASKS	MATH INVOLVED	SKILLS USED	MATH AIDS, TOOLS	CURRICULUM (Comments/Suggestions)
Manager SL1 Systems	Resolve production flow problems. Update Div. Man.	C M G A S GR ✓ ✓ ✓ ✓ ✓ ✓	Monitor meetings; inspect and process analytic thinking.	Assembly Drawings	
Industrial Engineer/ Specialists; Value Management and Financial Planning.	Document coordination program; Coordinate time sheet submission; Compare operational and book; Capacity of machines.	✓ ✓ ✓ ✓ ✓ ✓	Typing; extensive use of Personal Computer	Virtual machine VM 370; Simulation; Math Models; Lotus 1-2-3 S/W; Graphic packs.	Help develop logical thought processes; Communication skills; Recognition of relationships; Analytic skills. Emphasize applications; Experience in recognizing appropriate method; submit solution as a report.
Technologist in Packs Engineering	Support Prod. Shop; Troubleshoot components and processes.	✓ ✓ ✓ ✓ ✓ ✓	Thinking logically and analytically; Human relations; Coordinating people	Yield reports assembly drawings schematics; Spread Sheet S/W Test layout S/W	
SL 1 Manufacturing CIM Process innovation	Develop concept and implement innovation of vertical testing design; document H/W write S/W; Integrate	✓ ✓ ✓	Analytical; Computer design of H/W and S/W; visual;logical thinking; S/W design; Coordinating.	Math modelling; Statistical interpretation; sketching; computer S/W programs	
	Coordinate design of new product; redesign buffer; strategic cost improvement	✓ ✓ ✓ ✓ ✓ ✓	Manual, visual; financial analysis; analytic sequencing; communication	IBM P.C.; calculator; word processing	
SL1 Elec. Engineering	Improve present test process; implement new cost effective methods; support production shop	✓ ✓ ✓ ✓ ✓ ✓	Visual; analytic (D/M); coordinating; programming	IBM P.C.; scheduling spread sheets; drawings; calculator; word processing	Logical thinking; change methods? need more business/ accounting courses relating to university courses.

SUMMARY OF RESPONSES TO BASIC SCHEDULE BY

TECHNOLOGY, MARKETING, AND BUSINESS SYSTEMS INTERVIEWEES

JOB TITLE	TASK	MATH INVOLVED	SKILLS USED	AIDS/TOOLS	COMMENTS/SUGGESTIONS
Design Engineer Grade 7 (Technology)	Power dissipation and efficiency circulations Design calculations Measuring lengths for optimal fit etc.	C M Ge Al St Gr ✓ ✓ ✓ ✓ Ge - Analyse CRT data A - Select components Gr - For presentations Laplace, Fourier transform. for circuit analysis	Calculator Precision ruler Computer	Manual Electronic (Calc., H.P. computer N.T. data base)	More # calculations on mortgates, amortization, etc. Relate univ. abstra math to engineering
Manager Competitive Analysis and Market Research (Marketing)	System traffic capacities Competitive pricing Market studies	C M Ge M St Gr ✓ ✓ ✓ Used in tasks		V.D.T. for accessing data bases	Incorporate practic applications and include more math in financially oriented courses
Product Specialist SL-1 International (Marketing)	Maintain integrity S/W levels Analyse problems (PRTS) - to determine discovery and fix rates	C M Ge M St Gr ✓ ✓ ✓ ✓ ✓ Gain insight in PRTS work by plotting/ tracking statistics			Include more comput training, graphing spread sheets More model analysis and role playing Emphasize realistic math
Computer Prog. Analyst (Business Systems)	Maintain, implement payroll, purchasing systems in their manufacturing and financial aspects Basic calculations	C M Ge M St Gr ✓ ✓ Calculations related to no. hours worked on various projects	Analysis of feasibility of project Design, code, implement computer systems	S/W tools (COBOL, Powerhouse) H.P. 3000	Provide extra problems in areas o student weakness Help student's own initiative
SP 108 Programmer (Business Systems)	Gather statistics Prepare time sheets Write/test programs Analyse and extrapolate data to solve assignments	C M Ge M Al St Gr ✓ ✓ ✓ ✓	Analytical log-thinking (process flow)	P.C. S/W Calculator Flow charts H.P. 3000	More procedural prog. languages Use of P.C.s Be careful of how calculator is used

SUMMARY OF RESPONSES TO BASIC SCHEDULE BY
CONTROLLER AND HUMAN RESOURCES INTERVIEWEES

JOB TITLE	TASK	MATH INVOLVED	SKILLS USED	AIDS/TOOLS	COMMENTS/SUGGESTIONS
Senior Financial Analyst (Controller)	Budgets, quarterly forecasts Evaluation of returns for new products Inc. St./Bal. Sheet analysis	C M Ge M Al St Gr ✓ ✓ ✓ ✓ ✓ (R.O.I. etc.?)	Trend analysis Forecasts	H.P. 150 P.C. H.P. IBM Main-frames	Present real world problems which can be solved in more than one way Develop creative thinking vs. regurgitation
Specialist Systems and Procedures (Human Resources)	Calculations of average age, years of service in reports Completion of benefit profiles	Related calculations	Visual scanning	S/W programs for needed calculations	More emphasis on new technology methods and machines Introduction to business methods to prepare for later e.g., case studies, setting up own business
SPR 04 Specialist (Co-op of Student) (Human Resources)	Study current manual reports and computer print-outs Use W/P for documen-tation Verify population data Draw flow charts e.g., flow of headcount info.	C M Ge Al St Gr ✓ ✓ ✓ ✓ ✓ ✓ Understand formulae Basic addition and subtraction Prepare graphs Ratio occasionally Solve one-variable equations	Visual scanning Analysis of flow etc. in systems Discussions Deciding on work priorities	Calculator Computer W/P and Doc. processor S/W and System documentation manuals	Expose to more real life examples to maintain interest and motivation De-emphasize some repetitive aspects (leave to computer)

ATTACHMENT II

"LOWER-ORDER" MATHEMATICAL-TYPE ACTIVITIES AND PROCESSES

A. INSTRUMENT NUMBER TWO

B. SUMMARY OF RESPONSES FROM MAJOR ORGANIZATIONAL AREAS

I. PRODUCTION WORKERS

II. MANUFACTURING ENGINEERING

III. TECHNOLOGY

IV. QUALITY, BUSINESS SYSTEMS AND CONTROLLER

V. HUMAN RESOURCES

INSTRUMENT NUMBER TWO

A TAXONOMY OF ACTIVITIES AND PROCESSES INVOLVED IN DOING MATHEMATICS

PART I - LOWER ORDER PROCESSES

ACTIVITY/PROCESS	DESCRIPTION OF TYPICAL TASK AND WHETHER/HOW EACH ACTIVITY OR PROCESS IS USED IN IT
Comparing/Contrasting Sorting, Classifying Relating	
Abstracting	
Describing Representing Symbolizing	
Analyse data Generalise Conjecture/Hypothesize Transform Try-out, test Deduce/make logical inferences	
Demonstrate Explain Justify Verify/Reject Validate	
Interpret Communicate Report	

SUM[redacted] OF [redacted]ONS[redacted] QU[redacted]ONNAIRE
ON USE OF LOWER-ORDER "MATHEMATICAL-TYPE"
ACTIVITIES OR PROCESSES
I PRODUCTION WORKERS

ACTIVITY/PROCESS	JOB TITLE AND AREA OF WORK INVOLVED					
	Manual Operator Grade 23 Manual Assemble	Production Tester Grade 24 Repair Testing	Machine Operator Grade 26 Machine Insertion	Machine Set up/operator Grade 27 Machine Insertion	Electrical Engineering Technician Grade 27 Repair Testing	Electrical Engineering Technician Grade 27 Repair Testing
Comparing/Contrasting Sorting, Classifying Relating	components and parts	choose right board and program	discriminate between components decide what sequences of operations to use	compare sample boards with one on machine	decide between good/bad signals classify problem causes of faults	compare voltages, current- against reference levels. Check standard specification
Abstracting	make suggestions for improvements	suggestions for improvements*	make suggestions	make suggestions (example given)	when eliminating variables causing problems	when eliminating one likely cause of fault after another
Describing Representing Symbolizing	when using coding on components	use symbols in programs	use dravings and symbols	writes programs and changes them as needed using instructions provided*	use Oscilloscope to show wave forms, and detect faults	use Oscilloscope and meters*
Analyse data Generalise Conjecture/Hypothesize Transform Try-put, test Deduce/make logical inferences		analyse data from machine* speculate on cause of failure. If not shorts, then opens so clean contacts	machine or component problem, guess what is wrong. Test, check using logical thinking	detecting errors. exploring print-outs. Make routine tests	circuit problem,(LED on capacitor) analyse and follow chain of logical reasoning to find cause	use all of these. guess test use logic
Demonstrate Explain Justify Verify/Reject Validate	explain working to new employee	tell Gr. 27 if problems still there after test	verbally describe problems with new materials on sample board	explain changes to operator when modifies tape	show fault to engineer. Justify what you did	explain why X is not working after test
Interpret Communicate Report	fill in daily work sheet. No. of boards assembled, time taken	daily test report	check dravings and info. against machine operation Daily log of jobs	deal with "hot list" of boards. Talk to engineer after modification	ongoing discussions with engineers. Complete tally sheet	write out and communicate test results

*added after consultation with section managers.

SUMMARY OF RESPONSES TO QUESTIONNAIRE
ON USE OF LOWER-ORDER "MATHEMATICAL-TYPE"
ACTIVITIES AND PROCESSES
II MANUFACTURING ENGINEERING

ACTIVITY OR PROCESS	JOB TITLE AND AREA OF WORK INVOLVED		
	SPECIALIST	ENGINEER	ENGINEER
	FINANCIAL PLANNING	SL I SYSTEM ENGINEERING INNOVATION AND DESIGN	IMPROVING TEST PROCESS FLOW
Comparing/Contrasting Sorting, Classifying Relating	constant sorting and other related comparison activities to deal with influx of information	constant use-the essence of engineering and design	study present process to understand main features and events
Abstracting	integral part of refining information to be used	need to convert most data into costs, engineering equations, calculations, diagrams.	identify drawbacks and brainstorm to identify possible changes.
Describing Representing Symbolizing	constant use e.g. in preparing a spread sheet	almost all ideas are transformed into symbols, graphs, charts, or engineering sketches to manipulate and/or consolidate them	visit other company plant to enable better description of possibilities by comparison with way similar task is performed there.
Analyse data Generalise Conjecture/Hypothesize Transform Try-out, test Deduce/make logical inferences	constant use e.g. preparing a budget	need to refine ideas of project by detailed examination and repeated iteration	compare, analyse present process against results of inhouse and other ideas for improving process Analyse cost benefit
Demonstrate Explain Justify Verify/Reject Validate	constant use e.g. Refining a budget	need to 'sell' total project to peers and managers. Defend and modify all data as necessary	issue memos, change floor plan for process and implement as per agreed schedule
Interpret Communicate Report	used daily in personnel interfacing e.g. presenting budget to management	have to communicate full documentation-overall specifications, drawings, software descriptions, operating, maintenance instructions	demonstrate cost benefit through explanation of cost improvement at meeting of all concerned. Iron out any problems

SUMMARY OF RESPONSES TO QUESTIONNAIRE
ON USE OF LOWER-ORDER "MATHEMATICAL-TYPE"
ACTIVITIES OR PROCESSES
III TECHNOLOGY

ACTIVITY/PROCESS	JOB TITLE AND AREA OF WORK INVOLVED		
	DESIGN ENGINEER	SOFTWARE DEVELOPER	DESIGN ENGINEER
	SOLVE PROBLEM OF TERMINAL LOSING DATA	SOFTWARE DESIGN PROCESS	CIRCUIT DESIGN FOR POWER ASPECTS OF SC-1 PBX
Comparing/Contrasting Sorting, Classifying Relating	study problem, collect information	compare functional requirements of design with existing software to determine design approach	divide each circuit into analysable small sections similar to other designs
Abstracting	focus on various instructions,	determine design and data structures	define the functions of these blocks and calculate components needed
Describing Representing Symbolizing	loops etc. in software coding and program	carry out coding	select standard manageable components to meet defined functions
Analyse data Generalise Conjecture/Hypothesize Transform Try-out, test Deduce/make logical inferences	make, test and reject numerous hypotheses on basis of analysis of further information from tests process is recursive	test new software to determine interactions with existing software	measure in order to verify design intent and component selection
Demonstrate Explain Justify Verify/Reject Validate	find actual fault (pointers used for a circular Queue were unintentionally being incremented Modulo 128)	measure against acceptable criteria to ensure s/w fits functional requirements with no errors	test; catalogue and present information to be published
Interpret Communicate Report	find and implement easy solution!	produce design document	simplify all questions and concerns and answer all basic questions (problems; costs; changes)

SUMMARY OF RESPONSES TO QUESTIONNAIRE
ON USE OF LOWER-ORDER "MATHEMATICAL-TYPE"
ACTIVITIES OR PROCESSES
IV QUALITY, BUSINESS SYSTEMS AND CONTROLLER

ACTIVITY/PROCESS	JOB TITLE AND AREA OF WORK INVOLVED		
	QUALITY ENGINEER	BUSINESS SYSTEMS PROGRAMMER	SR FINANCIAL CONTROLLER
	CUSTOMIZED SOFTWARE DEVELOPMENT	ANALYSIS, DEVELOPMENT AND IMPLEMENTATION OF PROGRAM	FORECASTING AND FINANCIAL STUDIES
Comparing/Contrasting Sorting, Classifying Relating	given commercial specification, analyse individual customer needs	determine high level components in flow chart of process	use regularly 30% of time
Abstracting	develop feature definition by interpreting commercial spec. internally and technically	think how the identified components fit together	use regularly 5% of time
Describing Representing Symbolizing	develop design documentation code	put the process on paper; may describe in more than one way	USE
Analyse data Generalise Conjecture/Hypothesize Transform Try-out, test Deduce/make logical inferences	conduct internal testing and field trial restricted to one customer site	do detailed flow diagram; determine best solution; test logic by following the process on paper	REGULARLY 30% OF TIME
Demonstrate Explain Justify Verify/Reject Validate	expand testing to a set (6-8) of controlled sites	put process into a program and test it out on the computer to validate results	
Interpret Communicate Report	conduct product sample review of each previous phase, analyse results and release product when satisfactory	instruct users how to use system; prepare documentation for user and programmer audience	use regularly 35% of time

SUMMARY OF RESPONSES TO QUESTIONNAIRE
ON USE OF LOWER-ORDER "MATHEMATICAL-TYPE"
ACTIVITIES OR PROCESSES
V HUMAN RESOURCES

ACTIVITY/PROCESS	SYSTEM SPECIALIST	SPECIALIST
	COMPILE DATA, COMPLETE REPORTS ON PENSIONS, BENEFITS	DESIGNING AND IMPLEMENTING AUTOMATED POPULATION REPORTING SYSTEM
Compare/Contrasting Sorting, Classiflying Relating	sort out relevant documents, regulations	group departments under the correct manager
Abstracting		decide what data, future requests will be necessary for managers in decentralized syster
Describing Representing Symbolizing	enter data on calculator or computer for calculation	flow-chart the flow of information from source to user of current reports on population
Analyse data Generalise Conjecture/Hypothesize Transform Try-out, test Deduce/make logical inferences	do calulations yielding cost of benefits	using computer data base, carry out inquiry to educe statistics likely to show trends in absence from work
Demonstrate Explain Justify Verify/Reject Validate	complete benefits profile	design a cost improvement case to establish savings ($ and time) by automating a manual process
Interpret Communicate Report	send report out or give to superior	hold and relay results of discussions with 'consumers' of system as to how change may affect them

ATTACHMENT III

BASIC CONCEPTS AND TOPICS IN
SCHOOL MATHEMATICS (AGES 5-16)

A. TAXONOMY

B. QUESTIONNAIRE (INSTRUMENT NUMBER THREE)

C. SUMMARY OF 15 RESPONSES (TABLE I)

ROUGH TAXONOMY OF BASIC (ESSENTIAL OR IMPORTANT)
CONCEPTS AND TOPICS IN SCHOOL MATHEMATICS TO AGE 16

CONCEPTS/TOPICS	BRIEFER DESCRIPTION	RELATED PRACTICAL ACTIVITIES
1. NUMBER AND NUMERICAL RELATIONSHIPS		
Count and use skill in context for positive and negative integers.	COUNTING	
Place value (to 4 digits)	PLACE VALUE	
Select appopriate arithmatic operation.	DECIMAL and	
Use decimal system in practical contexts.		
Use simple fractions in apprpriate contexts.	COMMON FRACTIONS	
Use "understood" computational methods.		
Use scientific notation and standard form.	SCIENTIFIC NOTATIONS	Develop skill in estimating, and measuring in practical situations.
Use intelligently estimation, approximation and "number sense".	ESTIMATION,	
Use ideas of accuracy, and tolerance limits in practical contexts.	ACCURACY.	
2. MONEY		
Recognise coins and notes.	COIN, NOTES	
Know and use money conversions and relationships with confidence.	CONVERSION	
Carry out simple transactions - without a calculator - either mentally or on paper. Carry out more complex calculations or transactions using any appropriate method.	TRANSACTIONS	Do transactions in practical (real) situations.

3. PERCENTAGES		
Understand a percentage as 1 in every hundred. e.g. 1 per cent means 1c in every dollar.	MEASURING	
Calculate a percentage of i) a sum of money ii)a real quantity or thing.	CALCULATIONS	
Change (increase/decrease) a sum of money by a given percentage.	CHANGES.	Make appropriate purchases.
Appreciate every day uses e.g. for compound and into 100 point scale of reference.		
4. USE OF CALCULATOR		
Use efficiently for all four arithmetic operations, and fraction-decimal conversion.	EFFECTIVE use	
Appreciate importance of ordering operation.	ORDERING OPERATIONS.	
Be able to approximate as needed from calculation display digits.	APPROXIMATION	
Be able to check reasonable of calculator-obtained results.	CHECKING	
Make use of substitution in simple formulae, whether worded or symbolic.	SUBSTITUTION in FORMULAE.	
5. TIME		
Tell and understand times on 12 hr. and 24 hr. clock - analogical and digital.	TELL AND UNDERSTAND	
Calculate time intervals, and finishing times.	TIME INTERVALS	
Use timetables, and conversion charts.	TIMETABLE.	
Solve simple t,d,v problems.	PROBLEMS.	

6. MEASUREMENT		
Measure length, weight and capacity using, appropriate metric units.	MEASURE IN METRIC UNITS.	
Understand major relationships and equivalences between different suits and multiple metric units of length, mass, and capacity.		
Be able to relate sizes of metric units to common objects.		
Use basic imperial units of length, weight and capacity and know their approximate metric equivalents.		
Understand and use simple rates.		
Read meters and dials of various types.		
Relate estimation, measurement and approximation by means of practical activities in other curricular areas.	RELATE UNITS TO OBJECTS	
Imperial Units. Simple Rates, Meters, Dials.		
7. GRAPHS AND PICTORIAL REPRESENTATION		
Organise systematically the collection and tabulation of simple data.	DATA, COLLECTION, TABULATION	
Read, interpret and extract specific information from simple graphs and charts.	READ, INTERPRET.	
Construct simple graphs and charts.	CONSTRUCT GRAPHS and CHARTS.	Develop approximate hand-eye skills of neatness and accuracy in manipulative activity.
Extract information from numerical tables.		
Be exposed to and able to discuss critically visual numerical information presented in varied forms.	VARIED FORMS OF VISUAL INFORMATION	
Interpret a simple flow-chart, and develop appropriate if.....then statements from practical examples.	FLOW-CHARTS	

8. SPATIAL AND MECHANICAL CONCEPTS

Recognize and name simple plane figures (including the circle) and use related terms e.g. angle.	SIMPLE PLANE FIGURES	
Appreciate the properties of parallelism and perpendicularity.	PARALLEL PERPENDICULAR	
Be able to measure angles in degrees.	MEASURING	
Draw a simple plane figure to given specifications.	DRAWING ANGLES, PLANE FIGURES.	Use and develop skills with ruler, compasses set square, compasses.
Recognize and name common solid shapes.	SOLIDS AND	
Represent 3D figures in 2D.	NETS..	Build 3D solids from 2D drawings.
Recognize 2D drawing corresponding to 3D solid.		
Design simple objects like tables, snapshot album.	DESIGNING and MAKING.	Use plans of models, dress patterns, scale drawings photographs, maps.
Find perimeter and area of a rectangle.	MEASURING of	Use calculator, estimate, check reasonableness of result.
Find volume of a rectangular solid	RECTANGLE,	
Understand and use $C=\pi d$. ($\pi \doteqdot 3+$)	CIRCLE.	
Appreciate concept of scale and use of coordinates in drawings and maps.	SCALE	Make drawings to scale of plans, elevations, houses neighbourhood areas.
understand concept of bearings and how they are measured.	BEARINGS.	
Be able to visualize and understand simple mechanical movement, including simple linkages.	MECHANICAL MOVEMENT	Work with bicycle gears, car jacks, up and over garage doors.
Relate to elementary kinematics, relative motion, Newton's Laws, friction, elementary electricity, power.	ELEMENTARY MECHANICS and ELECTRICITY	Observe and work with real objects e.g. pulleys planes, cars, electric apparatus.

9. RATIO AND PROPORTION		
Understand the use of ratio with mixtures and recipes	RATIO	Mix quantities, make juice, cookies etc. make models.
Understand informally simple ideas of direct and inverse variation.	VARIATION	
10. STATISTICAL IDEAS		
Appreciate basic ideas of randomness and variability.	RANDOMNESS VARIABILITY	Play appropriate games. Use calculator, computer,
Know the meaning of probability and odds in simple cases.	PROBABILITY ODDS.	dice, spinners etc.
Understand meanings purposes and differences of mode, median and mean as measuring of average.	CENTRAL TENDENCY	Work with newspaper material, notes written and
11 ELEMENTARY ALGEBRA		
Use symbols to represent variables show correspondence between operations in arithmetic and algebra.	VARIABLE GENERALISED ARITHMETIC	Show variations in real life, also using films and models.
Use symbols in formulae and graphs.		
Solve simple problems using equations.		
12 USE OF THE COMPUTER		
Learn operation of the microcomputer, especially using it as a data base, spread sheet calculating graphical and decision making (if...then) tool.	DATA BASE CALCULATION GRAPHS, DECISION MAKING	Learn ongoing hands-on use of computer as a tool.
13 MANIPULATIVE AND OTHER SKILLS		
Develop manipulative skills of neat sketching and accurate drawing and measurement.		Sketch, make geometrical constructions and scale drawings, design and make objects.
Develop mental skills of estimation approximation, accuracy, mental arithmetic and number sense, especially.		
Develop calculator and computer skills.		Use calculator and computer.
Develop mechanical skills.		Work with objects, linkages.

QUESTIONNAIRE ON BASIC CONTENT/TOPICS/ACTIVITIES OF SCHOOL MATH CURRICULUM. AGES 6 - 16

1. Which of these topics do you consider
   i) essential (E) ii) Important but not essential (I) iii) unimportant (U)
   for a) the typical adult b) for your own job.

2. Are there other topics or experiences which you would include as important or essential? Please add them in the appropriate place.

3. Please make any other comments you think are helpful at the end as indicated.

SCHOOL MATH TOPICS	TYPICAL ADULT			YOUR JOB		
	Essential	Important	Unimport	Essential	Important	Unimport
1. NUMBER AND NUMRICAL RELATIONSHIPS						
i) COUNTING						
ii) PLACE VALUE						
iii) DECIMAL FRACTIONS						
iv) COMMON FRACTIONS						
v) SCIENTIFIC NOTATION						
vi) ESTIMATION, ACCURACY						
vii) SIMPLE ALGORITHMS						
2. MONEY						
i) COIN, NOTES						
ii) CONVERSION						
iii) TRANSACTIONS						
3. PECENTAGES						
i) MEASURING						
ii) CALCULATING						
iii) CHANGING						

	TYPICAL ADULT			YOUR JOB		
	Essential	Important	Unimport.	Essential	Important	Unimport
4. USE OF CALCULATOR						
i) EFFECTIVE USE WITH FOUR OPERATIONS AND F-D CONVERSION						
ii) ORDERING OPERATIONS						
iii) APPROXIMATING						
iv) CHECKING						
v) SUBSTITUTING IN FORMULAE						
5. TIME						
i) READ TELL AND UNDERSTAND						
ii) TIME INTERVALS						
iii) READ AND INTERPRET TIMETABLES						
iv) SOLVE SIMPLE PROBLEMS						
6. MEASUREMENT						
i) MEASURE IN METRIC UNITS						
ii) RELATE UNITS TO REAL OBJECTS						
iii) KNOW IMPERIAL UNITS, RELATIONSHIPS AND METRIC EQUIVALENTS						
iv) SIMPLE RATES						
v) METERS, DIALS						
vi) RELATE TO OTHER CURRICULAR AREAS						
vii) COMPOUND UNITS						
viii) EXPERIMENTAL ERROR						

	TYPICAL ADULT			YOUR JOB		
	Essential	Important	Unimport.	Essential	Important	Unimport
7. GRAPHS AND PICTORIAL REPRESENTATION						
i) COLLECT, AND TABULATE DATA						
ii) READ, INTERPRET, CONSTRUCT GRAPH AND CHARTS						
iii) KNOW AND DISCUSS VARIOUS FORMS OF VISUAL INFORMATION. ARROW-DIAG. VENN DIAG. TABLES						
iv) KNOW AND USE FLOW CHARTS						
8. SPATIAL CONCEPTS						
i) SIMPLE PLANE FIGURES						
ii) PARALLEL, PERPENDICULAR						
iii) MEASURE AND DRAW ANGLES AND PLANE FIGURES						
iv) SOLIDS AND NETS (3D FIGURES)						
v) DESIGN AND MAKE OBJECTS ETC.						
vi) MEASURE RECTANGLE AND CIRCLE						
vii) SCALE AND COORDINATES						
viii) BEARINGS						
9. BASIC MECHANICS AND ELECTRICITY						
i) MECHANICAL MOVEMENT						
ii) RELATIVE MOTION						
iii) NEWTON'S LAWS						
iv) ELEMENTARY ELECTRICITY						
v) POWER						

	TYPICAL ADULT			YOUR JOB		
	Essential	Important	Unimport.	Essential	Important	Unimport.
10. RATIO AND PROPORTION						
i) RATIO						
ii) VARIATION						
11. STATISTICAL IDEAS						
i) RANDOMNESS						
ii) VARIABILITY						
iii) PROBABILITY						
iv) ODDS						
v) CENTRAL TENDENCY						
12. ELEMENTARY ALGEBRA						
i) VARIABLE						
ii) GENERALISED ARITHMETIC						
iii) FORMULAE						
iv) EQUATIONS						
13. USE OF COMPUTER						
i) ACCESSING, RETRIEVING DATA						
ii) CALCULATIONS						
iii) GRAPHS						
iv) DECISION MAKING						
14. ANY OTHER COMMENTS						

Table I

SUMMARY FOR 14 TOPICS OF 15 RESPONSES TO "5-16" CONTENT QUESTIONNAIRE

	Topic	Number of Responses			Weighted Total Points
		Essential	Important	Desirable	
1	Counting	12	-	-	48
2	Place Value	4	8	-	32
3	Decimal Fractions	5	6		32
4	Meaning of Percent	5	10		40
5	Calculating Percent	5	10	-	40
6	'Changing' Percent	4	7		30
7	Four Operations With Hand Calculator	5	8	-	36
8	Simple Plane Figures	8	-	-	32
9	Parallel, Perpendicular	8	-	-	32
10	Read, Tell, Understand Time	5	7		34
11	Read and Interpret Graphs	3	9	-	30
12	Access/Retrieve Computer Data	10	3	-	46
13	Use Computer for Calculations	6	5	-	34
14	Use Computer for Tests and Decision Making	7	1	-	30

ATTACHMENT IV

INSTRUMENT NUMBER FOUR

USE OF SECONDARY AND POST-SECONDARY

MATH IN HIGH-TECHNOLOGY INDUSTRY

FINAL DRAFT
NOV 1985

(INSTRUMENT NUMBER FOUR)

USE OF SECONDARY AND POST-SECONDARY MATH IN HIGH-TECHNOLOGY INDUSTRY

This questionnaire is a first attempt to identify and map which mathematics topics and methods are used by professionals and managerial level personnel solving problems in high-tech industry. It is in two sections as follows:-

I DEMOGRAPHIC - Personal Professional Data

II TECHNICAL - A Areas and Levels of Mathematics

B Mathematical Methods and Approaches

C Emphasis of Mathematics used and Types of Problems solved.

I PERSONAL AND PROFESSIONAL DATA

NAME COMPANY

DIVISION/AREA

BRIEF JOB TITLE/DESCRIPTION

ACADEMIC QUALIFICATIONS

WORK EXPERIENCE AND RESPONSIBILITY (No. OF YEARS, FIRMS ETC.)

11 MATHEMATICAL LEVELS, CONCEPTS, METHODS AND PROBLEMS

A.1 Levels of Mathematics Used

Which levels of mathematics (secondary or post secondary) do you use?

Note: By secondary level is meant mathematics which is pre-calculus, and pre-inferential (i.e. descriptive only) statistics and which generally does not require "high level" thinking.

Please use your judgement.

	FREQUENTLY	OCCASIONALLY	SELDOM	NEVER
SECONDARY				
POST-SECONDARY				

2. Areas of Mathematics Used.

Which areas of mathematics do you use?

i) SECONDARY	FREQUENTLY	OCCASIONALLY	SELDOM	NEVER
TRADITIONAL ALGEBRA				
2D, 3D SYNTHETIC GEOMETRY				
COORDINATE (ANALYTIC) GEOMETRY				

SECONDARY	FREQUENTLY	OCCASIONALLY	SELDOM	NEVER
TRADITIONAL TRIGONOMETRY				
VECTORS AND MATRICES				
LINEAR PROGRAMMING				
DESCRIPTIVE STATISTICS				
SIMPLE PROBABILITY				

ii) POST SECONDARY

DIFFERENTIAL CALCULUS				
INTEGRAL CALCULUS				
COMPLEX NUMBERS				
FOURIER TRANSFORMS				
INFERENTIAL PROB. AND STATISTICS				
BOOLEAN ALGEBRA				
TOPOLOGY				

POST SECONDARY	FREQUENTLY	OCCASIONALLY	SELDOM	NEVER
ALEGRA SYSTEMS				
ADVANCED GEOMETRY				
COMBINATORICS				
MALVING				
COSTING				

B. Which mathematical methods and/or techniques do you use?

	FREQUENTLY	OCCASIONALLY	SELDOM	NEVER
ALGORITHMS				
SIMULATIONS				
MATH MODELLING				
OPERATIONAL RESEARCH				
STATISTICAL SAMPLING				
QUEUING THEORY				
COMPUTER METHODS				
i) DATA BASES				
ii) SPREAD SHEETS				
iii) GRAPHICS				
iv) TESTS (DECISION MAKING)				
v)				
vi)				
vii)				

C 1. To what extent do you use the following?

	FREQUENTLY	OCCASIONALLY	SELDOM	NEVER
AXIOMATIC SYSTEMS				
DISCRETE MATHEMATICS				
CONTINUOUS MATHEMATICS				
MODERN ADVANCED MATHEMATICS e.g. CATASTROPHY THEORY PLEASE SPECIFY AREA BELOW				
_____				
_____				
APPLIED MATHEMATICS				
i) (MECHANICS/ DYNAMICS)				
ii) (ELECTRICITY, ELECTRONICS)				
iii)(LIGHT)				
iv) (SOUND)				
v) (HEAT)				
CHEMICAL REACTIONS				
PROPERTIES OF MATHEMATICS				

	FREQUENTLY	OCCASIONALLY	SELDOM	NEVER
OTHER SCIENTIFIC DISCIPLINES, AREA INVOLVING MATHEMATICS				

PLEASE SPECIFY DISCIPLINE AREA AND USE (BELOW)

C 2. Outline the main type of problems involving mathematics which you need to be able to solve e.g. networks, circuit operations or design, sales forecasting, software development etc. Be as specific as you can in stating and describing them.

D. COMMENTS AND SUGGESTIONS

(Please make any comments, suggestions, etc. which may be useful in improving this questionnaire - and thanks for helping!)

D.H. CRAWFORD
SEPT. 1985

ATTACHMENT V

TWO ADDITIONAL QUESTIONNAIRES

A. OBJECTIVES IN SCHOOL MATHEMATICS

B. DESSIRABLE EMPLOYEE SKILLS AND QUALITIES

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Oct. 1985

A TAXONOMY OF OBJECTIVES FOR SCHOOL MATHEMATICS

These objectives hae been developed from a number of respected sources, including the N.C.T.M. publication An Agenda for Action and the U.K. report Mathematics Counts. They have been grouped in four categories - basic mathematical abilities, basic skills, appreciation of mathematics, and higher mathematical abilites.

I BASIC MATHEMATICAL ABILITIES

1. The student will be able to abstract and conceptualise mathematical ideas.
2. The student will be able to use mathematical symbolism as a means of representing objects and ideas.
3. The student will be able to be mathematically precise
4. The student will be able to reason inductively and deductively
5. The student will be able to generalise
6. The student will be able to see mathematics as a process, and as a creative activity.
7. The student will be able to communicate the results of the mathematics he does in in ordinary everyday language appropriate to his level of development.

II BASIC SKILLS

8. The student will be able to use mathematics as a tool in other subjects
9. The student will be able to use the calculator and computer as mathematical tools.
10. The student will be able to use the mathematical skills necessary for adult life.
11. The student will be able to use the mathematical skills necessary for employment.

III APPRECIATION OF MATHEMATICS

12. The student will become aware that mathematics exists everywhere in the environment.
13. The student will appreciate the power of mathematics as a concise unambiguous means of communication.
14. The student will appreciate the role and significance of mathematics in the history and development of civilization.
15. The student will recognize and appreciate mathematics as a system of patterns, relationships and structures.
16. The student will appreciate that engaging in mathematics can be a creative, aesthetic and satisfying endeavour.

IV ATTITUDES TO MATHEMATICS

17. The student will have positive attitudes to mathematics.
18. The student will demonstrate confidence in doing mathematics.

V. HIGHER MATHEMATICAL ABILITIES

19. The student will learn to understand and use the idea of mathematical proof.
20. The student will learn to understand and use the technique of mathematical modelling.
21. The student will develop the ability to find solutions to problem situations which involve mathematics.

c D.H. CRAWFORD
Oct. 1985

QUESTIONNAIRE ON OBJECTIVES FOR SCHOOL MATHEMATICS

Below are listed a number of objectives for all pupils studying school mathematics to age 16. They have been chosen as representing objectives listed as significant by respected professional sources, and are grouped in four categories.

1. If you know another objective which you think should be included please add it in the appropriate category.

2. For each objective listed, place a check mark in one of the columns opposite it, indicating whether you regard it as critical, important, desirable or insignificant.

OBJECTIVE	CRITICAL	IMPORTANT	DESIRABLE	INSIGNIFICANT
I BASIC MATHEMATICAL ABILITIES				
1. to abstract and conceptualise mathematical ideas.				
2. to use mathematical symbolism as means of representing objects and ideas.				
3. to be mathematically precise				
4. to reason inductively and deductively				
5. to generalise				
6. to see mathematics as a process, and as a creative activity.				

OBJECTIVE	CRITICAL	IMPORTANT	DESIRABLE	INSIGNIFICANT
II BASIC SKILLS				
7. Student will be able to use mathematics as a tool in other subjects.				
8. Student will be able to use the calculator and computer as mathematical tools.				
9. Student will be able to use mathematical skills necessary for adult life.				
10. Student will be able to use mathematical skills for employment.				

OBJECTIVE	CRITICAL	IMPORTANT	DESIRABLE	INSIGNIFICANT
III APPRECIATION OF MATHEMATICS				
11. Student will become aware that mathematics exists everywhere in the environment.				
12. Student will appreciate the power of mathematics as a concise unambiguous means of communication.				
13. Student will appreciate role and significance of mathematics in history and development of civilization.				
14. Student will recognise and appreciate mathematics as system of patterns, relationships and structures.				
15. Studentwill appreciate that engaging in mathematics can be creative, aesthetic and satisfying endeavour.				
IV ATTITUDES TO MATHEMATICS				
16. Student will have positive attitudes to mathematics.				
17. Student will demonstrate confidence in doing mathematics.				
V HIGHER MATHEMATICAL ABILITIES				
18. Student will learn to understand and use idea of mathematical proof.				
19. Student will learn to understand and use technique of mathematical modelling				
20. Student will develop the ability to find solutions to problem situations which involve mathematics.				

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Oct. 1985

SKILLS AND QUALITIES DEEMED DESIRABLE IN EMPLOYEES BY EMPLOYERS

This list of desirable skills and qualities has been developed mainly from industrial and educational sources encountered by the author while on sabbatical leave in the U.K. in 1985. They have been grouped in four categories - basic, analytic/synthetic, evaluative/creative, and (inter) personal).

I BASIC

The employee will be

1. literate
2. numerate
3. able to communicate effectively
4. able to think logically

II ANALYTIC/SYNTHETIC

The employee will be able to

5. analyse information and data
6. plan and organise
7. synthesize (think in terms of systems)

III EVALUATIVE/CREATIVE

The employee will

8. exercise good judgement
9. be willing to take responsibility
10. be action-oriented
11. be creative

IV (INTER) PERSONAL

The employee will be

12. realistic about success
13. tolerant of ambiguity
14. flexible
15. cooperative

c D.H. CRAWFORD
Oct. 1985

QUESTIONNAIRE ON DESIRABLE EMPLOYEE SKILLS AND QUALITIES

Below are listed a number of desirable employee skills and qualities, grouped in four categories - basic, analytic/synthetic, evaluative/creative, and (inter) personal.

1. If you know another skill or quality which you think should be included, please add it in an appropriate category.

2. For each skill quality listed, place a check mark in one of the four columns opposite, indicating whether you regard it as critical, important, desirable or insignificant for the ordinary employee leaving school at age 16.

SKILL OR QUALITY (ORDINARY EMPLOYEE)	CRITICAL	IMPORTANT	DESIRABLE	INSIGNIFICANT
I BASIC				
1. literate				
2. numerate				
3. able to communicate effectively				
4. able to think logically				
II ANALYTIC/SYNTHETIC				
5. able to analyse information and data				
6. able to plan and organise				
7. synthesize (think in terms of systems)				

SKILL OR QUALITY (ORDINARY EMPLOYEE)	CRITICAL	IMPORTANT	DESIRABLE	INSIGNIFICAN

III EVALUATIVE/CREATIVE

8. exercise good judgement
9. be willing to take reponsibility
10. be action-oriented
11. be creative

IV (INTER) PERSONAL

12. realistic about success
13. tolerant of ambiguity
14. flexible
15. cooperative

APPENDIX VII

SOME SOURCES OF INFORMATION USED IN THE STUDY

FEDERAL GOVERNMENT DEPARTMENTS AND COUNCILS

Department of Immigration and Employment
Place du Portage
Hull, P.Q.

Department of Regional Industrial Expansion
235 Queen's Street
Ottawa, Ontario
K1A 0H5
(613) 995-2235

Economic Council of Canada
P.O. Box 527
Ottawa, Ontario
K1P 5V6

National Research Council of Canada

Statistics Canada

Science Council of Canada
100 Metcalfe Street
Ottawa, Ontario
K1P 5M1

Supplies and Services, Canada
Place Du Portage 4B3
11 Laurier Street
Hull, P.Q.

NATIONAL ASSOCIATIONS

Canadian Advanced Technology Association (CATA)
Suite 803
275 Slater Street
Ottawa, Ontario
(613) 236-6550

Canadian Business Equipment Manufacturers Association (CBEMA)
Suite 212
1 Yorkdale Road
Toronto, Ontario
M6A 3A1
(416) 789-0508

Canadian Information Processing Society (CIPS)
243 College Street, 5th Floor
Toronto, Ontario
M5T 2Y1
(416) 593-4040

Canadian Manufacturers' Association (CMA)
1 Yonge Street
Toronto, Ontario
M5E 1J9
(416) 363-7261

Electrical and Electronic Manufacturers Association of Canada
(EEMAC)
1 Yonge Street
Suite 160
Toronto, Ontario
M5E 1R1
(416) 862-7152

CENTRES OF TECHNOLOGY

Advanced Fibre/Plastic Composites Program
Centennial College
Ashtonbee Campus
Scarborough, Ontario
(416) 694-3241

Canadian Centre for Creative Technology
415 Phillip Street
Waterloo, Ontario
N2L 3X2
(519) 884-8844

Centre for Advanced Technology Education
Ryerson Polytechnical Institute
Toronto, Ontario

Ontario Robotics Centre
Peterborough, Ontario

Research Centre for High Technology
Management
Carleton University
Arts Tower, Room 901
Ottawa, Ontario
K1S 5B6
(613) 564-2869

CONSULTING FIRMS

The Coopers and Lybrand Consulting Group
145 King Street West
Toronto, Ontario
M5H 1J8
(416) 366-1921

Evert Communications Ltd.,
P.O. Box 3158
Ottawa, Ontario
K1Y 4J4
(613) 728-4621

M.B. Fosters Associates Ltd.
Information Systems Consulting
Andrex House
1st Floor, 190 Bronson Avenue
Ottawa, Ontario
K1R 6H4
(613) 230-4321

William G. Hutchison & Company Ltd.
Computer Industry Consultants
2025 Sheppard Avenue East
Willowdale, Ontario
M2J 1V7
(416) 498-5344

INVESTMENT FIRMS

McLeod, Young, Weir Ltd.
Commercial Union Tower
Box 433, Toronto-Dominion Centre
Toronto, Ontario
M5K 1M2
(416) 863-7747

PUBLICATIONS

High Technology
38 Commercial Wharf
Boston, MA
02110

Canadian Commerce; Innovation
Department of Regional Industrial Expansion
235 Queen's Street
Ottawa, Ontario
K1A 0H5

Third Wave Investing - The Canadian
High Technology Investment Review
Evert Communications Ltd.
Suite 508, 880 Wellington Street
Ottawa, Ontario
K1R 6K7

OTHER USEFUL ASSOCIATIONS*

AFIPS - American Federation of Information Processing
Suite 800
1815 North Lynn Street
Arlington, V.A.
22209
(703) 558-3680

ACM - Association for Computing Machinery
11 West 42nd Street
3rd Floor
New York, N.Y.
10036
(212) 869-7440

AEDS - Association for Educational Data Systems
1201 Sixteenth Street N.W.
Washington, D.C.
20036
(212) 822-7845

ASM - Association for Systems Management
Canadian Headquarters
181 University Avenue
Suite 1802
Toronto, Ontario
M5H 3M7
(416) 364-4018

AISP - Association of Information Systems Professionals
Canadian Headquarters
141 Adelaide Street West
Suite 705
Toronto, Ontario
M5H 3L5
(416) 862-1415

ARMA - Association of Records Managers and Administrators
P.O. Box 6587
Station A
Toronto, Ontario
M5W 1A0
(416) 366-260

ACS - Australian Computer Society
GPO Box 4944
Sydney, N.S.W. 2001
Australia

* Extracted from 1985/86 CIPS National Membership Directory

BCS - British Computer Society
13 Mansfield
London, England
W1M OPB

CAD/CAM Technology Advancement Council
Office of Industrial Innovation 6E
235 Queen Street
Ottawa, Ontario
K1A 0H5

CATA - Canadian Advanced Technology Association
275 Slater Street
Suite 803
Ottawa, Ontario
K1P 5H9
(613) 236-6550

CADAPSO - Canadian Association of Data Processing Service Organizations
280 Albert Street
Suite 804
Ottawa, Ontario
K1P 5G8
(613) 230-3524

CAIS - Canadian Association for Information Science
Secretariat
44 Bayswater Avenue
Suite 100
Ottawa, Ontario
K1Y 4K3

Canadian Association of Software Developers
185 Bloor Street East
Suite 500
Toronto, Ontario
M4W 3J3
(416) 922-1153

CBEMA - Canadian Business Equipment Manufacturers Association
211 Consumers Road
Suite 300
Willowdale, Ontario
M2J 4G8
(416) 493-8710

CICA - Canadian Industrial Communications Assembly
235 Yorkland Boulevard
Suite 300
Willowdale, Ontario
M2J 4Y8
(416) 499-4222

CIM - Canadian Institute of Management
2175 Sheppard Avenue East
Suite 110
Willowdale, Ontario
M2J 1W8
(416) 491-2982

CMS - Canadian Micrographic Society
2175 Sheppard Avenue East
Suite 309
Willowdale, Ontario
M2K 1W8
(416) 499-6552

CORS - Canadian Operation Research Society
P.O. Box 6975
Station A
Toronto, Ontario
M5W 1X7

COACH - Canadian Organization for Advancement of Computers in Health
10504A - 169 Street
Edmonton, Alberta
T5P 3X6
(403) 489-4553

CSA - Canadian Standards Association
178 Rexdale Boulevard
Rexdale, Ontario
M9W 1R3
(416) 747-4363

DPMA - Data Processing Management Association
Canadian Headquarters
1501 Carling Avenue
Suite L8
Ottawa, Ontario
K1Z 7M1
(613) 728-1962

ECOO - Educational Computing Organization of Ontario
252 Bloor Street West
Toronto, Ontario
M5S 1V6
(416) 923-6641

ICCP - Institute for Certification of Computer Professionals
2200 East Devon Avenue
Suite 268
Des Plaines, Illinois
60018
(312) 299-4227

IEEE - Institute of Electrical & Electronic Engineers
Canadian Headquarters
7061 Yonge Street
Thornhill, Ontario
L3T 2A6
(416) 881-1930

IWP - International Word Processing Association
1015 North York Road
Willow Grove, P.A.
19090
(215) 657-5300

National Computer Graphics Association
8401 Arlington Boulevard
Fairfax, V.A.
22031
(703) 698-9600

WIP - Women in Information Processing
1333 Torresdale Avenue
Suite 2105
Willowdale, Ontario
M2R 3T2
(416) 499-1012